Mahdi Hassan

TEXT-BOOK OF GEOLOGY

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FOURTH EDITION, REVISED AND ENLARGED

VOL. II

London

MACMILLAN AND CO., LIMITED

NEW YORK: THE MACMILLAN COMPANY

1903

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PART VII. ERUPTIVE (IGNEOUS) ROCKS AS PART OF THE STRUCTURE OF THE EARTH'S CRUST.

THE lithological differences of eruptive rocks having already been described in Book II. (p. 195), it is their larger features in the field that now require attention,—features which, in some cases, are readily explicable by the action of modern volcanoes; and which, in other cases, by bringing before us parts of the economy of volcanoes never observable in any recent cone, reveal deep-seated rock-structures that lie beneath the upper or volcanic zone of the terrestrial crust. A study of the igneous rocks of former ages, as built up into the framework of the crust, thus serves to augment our knowledge of volcanic action.

At the outset, it is evident that if eruptive rocks have been extruded from below in all geological ages, and if, at the same time, denudation of the land has been continuously in progress, many masses of molten

Fig. 293.—Extensively-denuded Volcanic District (*B.*).

material, poured out at the surface, must have been removed. But the removal of these superficial sheets would uncover their roots or downward prolongations, and the greater the denudation, the deeper down must have been the original position of the rocks now exposed to daylight. Fig. 293, for example, shows a district in which a series of tuffs and breccias (*bb*) traversed by dykes (*aa*) is covered unconformably by a newer series of deposits (*d*). Properly to appreciate the relations and history of these rocks, we must bear in mind that originally they may have presented

some such outline as in Fig. 294, where the present surface (that of Fig. 293) down to which denudation has proceeded is represented by the dotted line *n s*.[1] We may therefore *a priori* expect to encounter different levels of eruptivity, some rocks being portions of sheets that solidified at the surface, others forming parts of injected sheets, or of the pipe or column that connected the superficial sheets with the internal lava-reservoir. We may infer that many masses of molten rock, after being driven so far upward, came to rest without ever finding their way to the surface. It cannot always be affirmed that a given mass of intrusive igneous rock, now denuded and exposed at the surface, was ever connected with any superficial manifestation of volcanic action.

Now, as a general rule, some difference may be looked for in texture, if not in composition, between superficial and deep-seated masses. The latter have crystallised slowly among warm or even hot rocks under considerable pressure, while the former have cooled much more rapidly

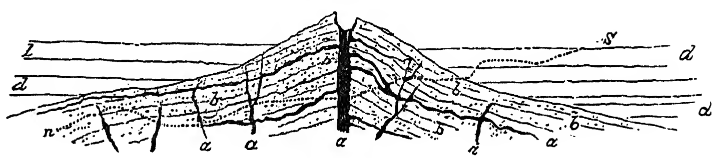

Fig. 294.—Restored outline of the original form of ground in Fig. 293 (*B*.).

in contact with the atmosphere or with chilled rocks. This difference is of so much importance in the interpretation of the history of volcanic action that it should be clearly kept in view. As the result of actual observation, it is found that those portions of an eruptive mass which consolidated at some depth are generally more coarsely crystalline than those which flowed out as lava; they are likewise usually destitute of the cellular scoriaceous structure and the ashy accompaniments so characteristic of superficial igneous rocks. Yet even if there were no well-marked petrographical contrast between the two groups, it would manifestly lead to confusion if no distinction were drawn between those igneous masses which reached the surface and consolidated there, like modern lava-streams or showers of ashes, and those which never found their way to the surface, but consolidated at a greater or less depth beneath it. There must be the same division to be drawn in the case of every active volcano of the present day. But at a modern volcano, only the materials which reach the surface can be examined, the nature and arrangement of what still lies underneath being matter of inference. In the revolutions to which the crust of the earth has been subjected, however, denudation has, on the one hand, removed superficial sheets of lava and tuff, thereby exposing the subterranean continuations of the erupted rocks, and, on the other hand, has laid open the very heart of masses which, though eruptive, seem never to have been directly connected with actual volcanic outbursts.

[1] De la Beche, 'Geol. Observer,' p. 561.

The progress of research among the eruptive rocks of the earth's crust has brought to light the following important facts regarding them. 1st, They are not distributed with invariable identity of petrographical characters over the globe, but are grouped in more or less distinct areas or provinces, in each of which a general family relationship may be traced among the different igneous masses.[1] This consanguinity in mineralogical composition and microscopic structure, though it may hold good on the whole throughout each province, may be found to vary considerably even in adjacent provinces, which are distinguished in turn by other peculiarities. 2nd, There has been in each distinct region a more or less definite sequence in the order in which the different rocks or varieties of rock have appeared, and this sequence, though its general features may be recognised as broadly similar everywhere, is subject to considerable local variations. 3rd, Not only has there been a process of differentiation in the magma reservoirs within the terrestrial crust, whereby the injected or ejected materials at the end of an eruptive cycle have come to differ, sometimes to a great degree, from those that appeared at the beginning, but even within the same igneous mass, after its expulsion from the reservoir into the crust, there has often arisen a separation of the mineralogical constituents, the more acid moving to one portion of the mass and the more basic to another. Some of these features have already been incidentally referred to in connection with modern volcanic action, but it is only where ancient eruptive rocks have been laid bare by denudation that the evidence is obtainable for a satisfactory discussion of the subject. Before entering, therefore, upon the consideration of the igneous rocks as part of the structure of the earth's crust, we may with advantage attend to the three facts just enumerated, which supplement and extend the conclusions deducible from a study of modern volcanoes.

1. **Petrographical Provinces.**—The example of these which has been most sedulously studied is probably that of the Christiania district, which has been so fully made known by the long-continued and detailed researches of Professor Brögger. He has shown that the eruptive rocks of that part of Scandinavia form a consecutive series, specially distinguished by its high percentage of soda, and including a number of types seldom observable elsewhere. He finds a genetic connection between the different members of this series. On the one hand are thoroughly acid rocks, including different varieties of granite and quartz-syenite, with acid quartziferous augite-syenite (Akerite), a peculiar intermediate group of basic augite-syenites (Laurvikite), nepheline-syenite (Laurdalite) and mica-syenite, and a thoroughly basic series comprising camptonites, bostonites, and olivine-gabbro-diabases.[2]

Another province which is distinguished by the petrographical character and sequence of its rocks is that of the Carboniferous region of the south of Scotland. It possesses a great development of andesites with some peculiar trachytes, and a copious series of more basic rocks, ranging from dolerites without olivine to basalts and limburgites.[3]

[1] J. W. Judd, *Q. J. G. S.* xlii. (1886), p. 54.

[2] 'Die Mineralien der Syenitpegmatitgänge,' Leipzig, 1890; "Basic Eruptive Rocks of Gran." *Q. J. G. S.* l (1894), p. 15; 'Die Eruptivgesteine des Kristianiagebietes,' Kristiania, 1894-98, and *ante*, p. 217.

[3] 'Ancient Volcanoes of Great Britain,' chaps. xxiv.-xxviii.

A marked petrographical province is to be found in the line of old Italian volcanoes which lies on the west side of the Apennine Chain from Tuscany to Naples. This tract is more especially characterised by the abundance of its leucitic rocks, which are sometimes accompanied by trachytes and other non-leucitic masses. Great variety among the volcanic products is displayed at each eruptive centre, yet the range of type remains tolerably uniform throughout.[1]

2. Sequence of Eruptive Rocks.—In various parts of the world, where a large connected series of eruptive rocks has been studied in some detail, a more or less distinct local order of succession has been ascertained to have marked the appearance of the several petrographic types of each province. Allusion has already (*ante*, p. 349) been made to evidence of such a sequence among the products of modern and still active volcanoes. But it is in the records of older volcanic and plutonic action, laid bare by prolonged denudation, that the evidence can be most fully perceived. As far back as 1868, Baron von Richthofen expressed his belief that from the observations made by him in Europe and in North America a general order of occurrence of eruptive rocks could be established, and this order appeared to him to be first Propylite, followed successively by Andesite, Trachyte, and Rhyolite, and ending with Basalt.[2] If the two first members of this series be regarded as practically different conditions of the same rocks, the order given by von Richthofen begins with material of intermediate composition, then passing through stages of increasing acidity reaches the rhyolites, and finally ends off with a thoroughly basic compound, viz. basalt.

Considerable difference of opinion exists as to whether any such order of appearance can be recognised as of general application, and still more as to the cause to which it should be assigned. This question has been investigated in great detail by Professor Brögger. He believes that the eruptive rocks of the Christiania district not only form a distinct petrographical province, but, as already stated, that they have a close genetic connection with each other, and appeared in a definite order according to chemical and mineralogical composition. They seem to be mostly of Devonian or Old Red Sandstone age, and occur as intrusive bosses and dykes as well as surface outflows. The earliest eruptions were strongly basic, consisting of olivine-gabbro-diabases. With these were associated dykes and sheets of camptonite and bostonite. Later came the nepheline-syenites, followed by the granitic rocks, while last of all came a multitude of basic intrusions, now found in narrow dykes of diabase and allied types, often amygdaloidal.[3]

In the Eureka district, Nevada, Mr. Arnold Hague has ascertained that among the great Tertiary eruptions there displayed, the earliest consisted of hornblende-andesite and hornblende-mica-andesite, followed by dacite and then by rhyolite and rhyolitic pumice and tuff. He believes that the rhyolites were succeeded by pyroxene-andesites, and these are closely related to the basalts, which form the latest of the series.[4]

In the Yellowstone Park the order of eruption established by the members of the United States Geological Survey is andesite of mean composition, followed by eruptions of more basic andesite and basalt, and more siliceous andesite and dacite, and by basalt,

[1] De Stefani, *Bol. Soc. Geol. Ital.* x. (1891), p. 449; H. S. Washington, *Journ. Geol.* vols. iv. and v.

[2] "The Natural System of Rocks," *Californ. Acad. Sci.* 1868. An excellent historical summary of views regarding the internal magmas of the earth is given by Zirkel in his 'Lehrbuch,' i. pp. 458-471.

[3] See his Memoirs cited on pp. 217, 221.

[4] Monograph xx. *U. S. G. S.* p. 249.

rhyolite, and basalt, the order being locally modified in different districts, but the general succession being from a rock of average composition through less siliceous and more siliceous types up to rocks rich in silica on the one hand, and others extremely low in that constituent on the other.[1]

More recently Mr. J. E. Spurr has gathered all the evidence at present available regarding the succession and relations of the lavas in the Great Basin region of the Western United States. He thinks that an earlier acid group exists which is not developed in every district, and that when the whole sequence is complete it is as follows in order of appearance: (1) Rhyolite (granite and alaskite); (2) Andesites of various types, with gradual transitions to the following; (3) Rhyolite (sometimes with complementary olivine-basalt); (4) Andesite of various types with gradual transitions to the next group; (5) Basalt (sometimes with complementary rhyolite). Between Nos. 1 and 2 and between 3 and 4 there is a break indicating a long lapse of time.[2]

A remarkable sequence has been found by Messrs. Lawson and Palache in a long series of Pliocene eruptions among the Berkeley Hills near San Francisco. No fewer than five, possibly six, cycles have there been displayed, in which the same order of recurrence of volcanic material appears. In each of them the earliest discharges were of andesites, followed by basalt and that by rhyolite.

The most complete volcanic record yet described is that presented in the British Isles, where each great geological system from the Archæan to the Permian includes intercalated eruptive rocks. This extended chronicle comprises the detailed history of a long succession of volcanic cycles within a comparatively restricted area of the earth's surface. Each of these cycles probably endured for a protracted time, and the intervals between them may have been even more prolonged. From the Permian to the early part of the Tertiary periods there was a complete quiescence in volcanic activity, for in the Triassic, Jurassic and Cretaceous formations no vestige of any contemporaneous igneous rocks has been found. In older Tertiary time, however, the subterranean forces once more broke into eruption and piled up the extensive plateaux and hills of Antrim and the Inner Hebrides. There is thus a succession of volcanic records in which the materials can be arranged chronologically in the order of their appearance. The result of a study of these records is to show that each represents more or less completely a cycle of petrographical development. The earliest eruptions are generally intermediate or basic, and the rocks then become more siliceous, but the last are usually basic. In the basin of the Firth of Forth, where the Carboniferous volcanic series is most fully developed, the oldest eruptions consisted mainly of andesites, but included some more basic outflows. In East Lothian these rocks are overlain with a thick group of trachytes, which are accompanied by bosses of phonolite. But in the following or Carboniferous Limestone portion of the period the eruptions consisted mainly of basalts, often extremely basic. The Tertiary cycle is even more distinct in the west of Scotland. Above the denuded Chalk lies a thick pile of basalts, which towards the top are succeeded by or interstratified with trachytes and trachytic tuffs. Next come huge eruptive masses of gabbro, including peridotites. These are disrupted by granites and granophyres, while the youngest rocks of all are basalts in the form of dykes, which traverse all the other parts of the series.[3]

Whatever explanation may be given of it, there can be no doubt that a sequence in the order of appearance of eruptive rocks can be established in most districts where any extensive series of these rocks is displayed. The order does not appear to be quite the same in every region, and the differences are perhaps too great to be explicable on any of the hypotheses

[1] J. P. Iddings, "On the Origin of Igneous Rocks," *Bull. Phil. Soc. Washington*, xii. (1892), p. 145.

[2] *Journ. Geol.* viii. (1900), pp. 621-646.

[3] 'Ancient Volcanoes of Great Britain,' chaps. xxiv.-xxviii., xxxiii.-l.

that have been proposed. On the whole, however, there is reason to believe that the prevalent sequence is that above indicated, viz., from an intermediate to a more acid composition, with a concluding effusion of basic material. This subject is so closely connected with differentiation that it must be further considered in the following pages.

3. **Differentiation in Eruptive Rocks.**—This subject has been studied from two different sides, topographical and chronological. In the first place, single masses of rock exposed at the surface have been carefully examined, with a view to determine the nature of the obvious petrographical differences that occur even in the same body of material; and, in the next place, the various separate eruptive masses in a province have been grouped in their order of appearance, and have been analysed chemically and microscopically, so as to reveal their gradations of composition and structure. In the one case, we have before us the differentiation of an intruded mass during its cooling and consolidation, in the other the evidence of heterogeneity or differentiation in the magma reservoir underneath, either existing at the time of active volcanism or developed during the course of long intervals of time, and manifested in the differences between successive discharges. Each of these heads has given rise to much discussion and a considerable addition to geological literature.

(*a*) In dealing with a single mass of rock, exposed at the surface, it is not difficult to gather the facts as to variations in texture and composition of its different parts, though there may be considerable diversity of opinion as to their explanation. An excellent example of the differentiation which may be detected in a single body of erupted material was described in 1892 by Messrs. Dakyns and Teall from Garabal Hill and Meall Breac in Argyllshire.[1] A large mass of biotite-granite, which has there invaded the mica-schists of the Highlands, passes from a porphyritic condition into tonalite (quartz-diorite). Along its south-eastern margin it is flanked by a belt of diorite, with which are associated ultra-basic rocks. There is thus a great body of acid material occupying some ten square miles, which becomes increasingly acid towards the margin, presenting intermediate varieties of hornblende-biotite granite, tonalite, diorite, and augite-diorite, the series terminating in such highly basic compounds as wehrlites (olivine-diallage rocks), picrites (olivine-augite rocks) and serpentine. The first rocks formed were peridotites, followed by diorites, tonalites and granites in the order of increasing acidity. The most acid portion of the whole mass occurs as narrow veins in the granite and tonalite, and consists of felspar and quartz with hardly any ferro-magnesian constituents.[2]

Another instance of remarkable differentiation within one body of erupted material has been studied by Mr. Harker in Carrock Fell, in the English Lake district.[3] This hill consists of an acid rock, having the structure of granophyre, with large associated masses of gabbro and diabase. The gabbro shows a remarkable increase of specific gravity and of basicity towards its margin. Its central portion has a density less than 2·85, abundant free quartz, and a maximum silica-percentage of 59·46. From that condition it progressively changes to the outer border where the specific gravity rises above 2·95, the silica-percentage sinks to a minimum of 32·50, while the proportion of iron-ores amounts in places to a fourth of the whole rock. The granophyre is of younger date than the gabbro. It is an augite-granophyre, having 71·60 per cent of silica, but towards its margin, where it comes in contact with the most basic zone of the gabbro,

[1] *Q. J. G. S.* xlviii. (1892), p. 104.

[2] The basic margins of the Pyrenean granite are otherwise explained by Lacroix. *Postea*, p. 780.

[3] *Q. J. G. S.* l. (1894), p. 311 ; li. (1895), p. 125.

it loses its acid character, having incorporated some of the gabbro into its substance. In this case, the marginal modification is due to the caustic action of the acid rock upon another mass outside, and not upon any process of differentiation within the granophyre itself. A similar effect, previously described by Professor Sollas, is even more strikingly developed at the junction of granophyre dykes with the gabbro of Barnavave, Carlingford, Ireland.[1] And Mr. Harker himself has more recently described other striking examples of the same caustic action from the junctions of the granophyre with the gabbro of the Isle of Skye (*postea*, p. 776).

We thus perceive two causes which may in different cases produce marginal modifications in the structure and composition of eruptive rocks: 1st, an actual differentiation of their own substance, whereby the more basic and more acid constituents are separated from each other into different portions of the mass; and 2nd, a change due to the solution of the rocks with which an intrusive mass comes in contact, and the incorporation of more or less of the dissolved material into the younger body. It is obvious, however, that this latter cause must be at the best of merely local extent, and can hardly go far from the margin into the body of a large eruptive mass.

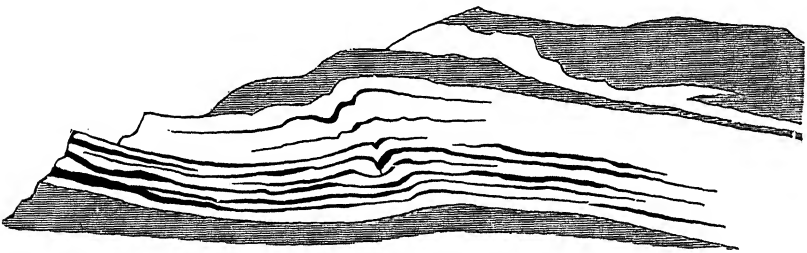

Fig. 295. Banded and puckered gabbro, Druim an Eidhne, Glen Sligachan, Skye.

(*b*) Evidence has multiplied in recent years that the processes of differentiation are carried on upon a large scale within the magma beneath the terrestrial crust. This evidence shows that in some cases during a period of continued eruptive activity, the magma has become separated into more basic and more acid portions, from each of which intrusions or discharges are made successively or simultaneously. The existence of such a heterogeneous magma is well illustrated by the banded gabbros and other similar rocks, where the materials have been injected or protruded simultaneously from sources of strikingly different chemical and mineralogical composition. Thus the Tertiary gabbros of Skye include rapid alternations of pale and dark bands, the former composed mainly of labradorite, with some augite, uralitic hornblende and magnetite, and containing 52 per cent of silica; the latter sometimes consisting of little else than augite and magnetite with only 29·5 per cent of silica. The bands are tolerably parallel to each other, but are lenticular or not continuous for a long distance. That they belong to the time of extravasation and not to any subsequent process of differentiation *in situ*, is shown by their occasional puckering and curvature. They were evidently disturbed while still in a plastic condition. These rocks present a striking resemblance to many ancient gneisses.[2]

[1] *Trans. Roy. Irish Acad.* xxx. (1894), p. 477; also *Geol. Mag.* 1900, p. 295.

[2] A. G. and J. J. H. Teall, *Q. J. G. S.* l. (1894), p. 645; A. G. *Compt. rend. Congrès. Géol. Internat.* Zurich, p. 139; 'Ancient Volcanoes of Great Britain,' ii. p. 341. Banded gabbros have also been described from the Radauthal by Lossen, *Z. D. G. G.* xliii. (1891), p. 533; and by F. D. Adams, from the Saguenay district, *Neues. Jahrb. Beilageb.* viii. (1893), p. 452. This structure, which has been already noticed (p. 256), will be again referred to in connection with the Archæan gneisses (Book VI. Part I, § 1).

They form thick intrusive masses, which have disrupted the Tertiary basalt-plateaux of the Inner Hebrides. Another illustration of the simultaneous existence of basic and acid portions in the same active volcanic focus is supplied by the Lower Old Red Sandstone of Central Scotland, where among the andesitic and diabasic lavas there are intercalated contemporaneous sheets of acid dacite and breccias of rhyolitic or felsitic fragments.

(*c*) More usually the evidence, as above detailed, with reference to the sequence of eruptive rocks, indicates that the variation has been slowly progressive during the continuance of a volcanic period, so that the ejected materials at the end come to be considerably different in composition from what they were at the beginning. It is difficult to understand this petrographical sequence on any other ground than that it arises from a gradual separation of the constituents in the body of the subterranean magma. The more basic being the more readily separable may be expected to come first and to leave a more acid residuum for the later discharges. Reference may again be made here to Professor Brögger's investigation of the genetic relationship between the several types of rock which have made their appearance in the Christiania district. From the earliest of the series, which are the most basic, to the latest, which (except the final unimportant dykes of diabase) are the most acid, he has traced a continuous series of varieties, connected so closely together by passage-types that he regards it as impossible to doubt that they have all originated from a common source. Dealing with the oldest group, he thinks that the original basic magma which supplied the olivine-gabbro-diabases, that were pressed up to a higher level, afterwards underwent, at a deeper level, a process of differentiation whereby there was separated by diffusion a basic portion, which gave rise to the camptonite intrusions, while the more acid remainder supplied material for the bostonite dykes and sheets. This differentiation has not only taken place within the magma reservoir, but also in the dykes and sheets themselves, where it must have occurred after their injection into a higher level of the crust. Moreover, another type of differentiation occurs along the western and northern margins of the boss of Brandberget, where the olivine-gabbro-diabase has supplied a basic zone of almost pure pyroxenic composition, which has often crystallized as a coarse-grained pyroxenite, containing as much as 95 per cent of pyroxene. Again, in the laccolite of Viksfjeld, more acid quartziferous augite-diorites are frequent as the latest products of differentiation. Professor Brögger concludes that whatever may be our explanation of the cause of these variations, there can be no doubt that the differentiation has actually taken place; and that in this Christiania region one and the same magma under different conditions has been differentiated in different ways into different groups of rock, with distinct chemical compositions in their several members.[1]

The examples of a succession in the erupted materials among the Tertiary volcanic districts of the Great Basin and surrounding regions in Western North America, afford an instructive lesson as to the nature of the changes which may take place in the constitution of the material that fills a magma reservoir during the continuance of a volcanic period. With regard to the Eureka district, above cited, Mr. Hague remarks that all the erupted rocks may be referred to two sharply defined groups, one acid or felspathic, the other basic or pyroxenic. In the former the earliest and most basic portion consists

[1] *Q. J. G. S.* l. (1894), pp. 15-37. The subject is more extensively elaborated in his memoir on 'Die Eruptivgesteine des Kristianiagebietes.' In Part i. (pp. 123-158) he treats of the rocks of the Grorudite-Tinguaite series as products of differentiation; in Part ii. he describes the succession of eruptive rocks at Predazzo in the Tyrol, compares it with that of the Christiania district, and discusses the mechanism of the intrusion of deep-seated eruptive masses; in Part iii. (pp. 227-365) he enters fully into the genetic relations between the masses of Laurdalite and their accompanying dykes, and discusses the diffusion-hypothesis, the Kern hypothesis of Rosenbusch, and various explanations which have been proposed to account for the phenomena of differentiation.

of hornblende-andesite, which, merging insensibly into hornblende-mica-andesite, and graduating further by the addition of quartz into dacite, then by decrease and failure of hornblende and the appearance of orthoclase, passes into rhyolite. The oldest lavas of the pyroxene group were pyroxene andesites, which gradually pass into basalts. Mr. Hague believes it to be impossible to regard these differentiated volcanic products otherwise than as having been derived from an original common reservoir.[1]

Any theory which is proposed to explain this process of differentiation must take account of the considerations stated in the foregoing paragraphs with regard to the sequence of eruptive rocks, and more especially of the fact that the cycle of change in the composition of the magma has recurred again and again within the same limited district. In 1892 I pointed out this recurrence as singularly striking in the volcanic history of so limited an area as the British Isles, and remarked that "as the successive protrusions took place within the same circumscribed region it is evident that in some way or other, during the long interval between two periods, the internal magma was renewed as regards its constitution, so that when eruptions again occurred they once more began with basic and ended with acid materials."[2] Each of these periods in which this recurrence was repeated was termed by me a volcanic cycle. Their records are not always complete, sometimes the earlier and sometimes the later stages being unrepresented; but the general order of appearance of the rocks is maintained with remarkable persistence. Even more striking is the instance above cited from the Berkeley Hills, where within one comparatively small area no less than five cycles were completed in Pliocene time.

Various hypotheses have been proposed to account for such evident changes in large bodies of injected matter, and also in the magma-reservoirs during a long course of eruptions.[3] Some writers have supposed the original existence of differently constituted magmas which, erupted at different times or simultaneously and in different proportions, might explain the observed phenomena, Professor Rosenbusch, for example, has suggested the existence of some five or six such fundamental magmas. Among these the granitic magma is represented as including, besides granite, the old volcanic quartz-porphyries, and keratophyres, and the younger volcanic felsoliparites, pantellerites and trachytes; the gabbro-magma comprises, besides deep-seated and older volcanic rocks, such younger volcanic masses as basalt and leucitite.[4] M. Michel-Lévy tabulates four magmas, each capable of considerable subdivision. 1st, Alkaline (granulitic, granito-eleolitic, pantelleritic); 2nd, Alkaline-earthy (granito-tonalitic, granitic, proper); 3rd, Earthy-alkaline (diorito-diabasic, diabaso-lamprophyric); 4th, Ferro-magnesian (lamprophyric, peridotic). But he considers that only two magmas are susceptible of a truly precise

[1] Monograph. xx. *U. S. G. S.* pp. 253-268.

[2] *Q. J. G. S.* xlviii. (1892), p. 178. Anniversary Presidential Address.

[3] An excellent historical digest of opinion on this subject will be found in Mr. Idding's paper on "The Origin of Igneous Rocks," *Bull. Phil. Soc. Washington*, xii. (1892). His other contributions include papers in *Bull. Phil. Soc. Washington*, xi. (1890), p. 191; *Journ. Geol.* i. (1893), pp. 606, 833; *Q. J. G. S.* lii. (1896), p. 606. A review of opinion from an opposite point of view to that taken by Messrs. Brögger and Iddings is given by M. Michel-Lévy in his Note sur la Classification des Magmas des Roches Eruptives" *B. S. G. F.* xxv. (1897), pp. 326-377; also *op. cit.* xxiv. (1896), p. 123.

[4] Rosenbusch's 'Kern-Hypothese' is given in his paper of 1889, and somewhat modified in the 3rd edition of his 'Mikroskopische Physiographie,' ii. p. 384. It is summarised and commented on by Brögger in his 'Ganggefolge des Laurdalits,' iii. (1898), p. 302.

definition and possess a living individuality—the ferro-magnesian and the alkaline, which are fundamental and behave differently as eruptive masses, the former being the result generally of igneous fusion, the latter requiring the co-operation of mineralising or pneumatolitic agents, such as are seen in fumeroles (*ante*, p. 270), and to which he attaches vast importance. He believes that it is in the circulation of fluids charged with mineral solutions under pressure and a high temperature that we must seek the active agent in the differentiation which takes place in the reservoirs of eruptive magma.[1]

Other petrographers and geologists have endeavoured to account for the observed changes on the assumption that they have proceeded in each case from one original magma. Mr. Teall, in discussing the consolidation of molten magmas, proposed that they should be considered as solutions, and sought how far their behaviour could be explained by the analogy of different solutions which had been studied experimentally. He dwelt upon the significance of the researches of Guthrie on cryohydrates, and of Lagorio on the glassy base of igneous rocks. He first suggested the application to them of the discovery by Soret, which he defined thus: "A homogeneous solution remains homogeneous so long as the temperature remains uniform, but a disturbance in the equilibrium of temperature brings about heterogeneity in the solution. The compound or compounds with which the solution is nearly saturated tend to accumulate in the colder parts."[2] Various objections have been brought forward to the application of this principle as an adequate explanation of magmatic differentiation, and it is now admitted by Brögger that ordinary diffusion, whether by Soret's principle or in any other way, is insufficient to account for the facts.[3] Mr. Harker, dealing with that type of differentiation where a magma, supposed to be originally homogeneous, has had its more basic ingredients concentrated in the cooler marginal parts, compared such a magma with a saturated saline solution, and suggested that the migration of the least soluble constituents to the part of the liquid most easily saturated would determine crystallization, the process which, in the case supposed, would give the most rapid evolution of heat.[4]

Mr. G. F. Becker, in criticising the hypothesis of differentiation by diffusion, dwells on the stupendous amount of time which by the methods of Ludwig and Soret would, he thinks, be required for the segregation of magmas, even if they could be kept free from convection currents. He assumes that the magma within the earth must be at least as viscous as lava, and that in such a mass convection currents must necessarily come in to prevent any separation of constituents by diffusion from appreciably affecting the composition.[5] He has subsequently proposed another solution of the problem, so far, at least, as regards masses that have been erupted into the crust or up to the surface. Returning to the process of fractional crystallization, so well illustrated by the researches of Guthrie on eutectic mixtures, he remarks that a mass of erupted material, injected into a fissure or cavity among cold rocks, will be subjected to convection currents, and a

[1] See previous note, also *B. S. G. F.* xxvi. (1898), and *ante*, pp. 196, 199, for his notation to express the composition of the eruptive magmas.

[2] 'British Petrography,' 1888, p. 394. See also *Geol. Mag.* 1897, p. 553; and his Presidential Address to *Geol. Soc.* for 1901. H. Bäckström has remarked that Soret's principle applies only to very dilute solutions, and that we are still ignorant concerning the behaviour of concentrated solutions, especially with reference to this principle, *Journ. Geol.* i. (1893), p. 774. [3] *Op. cit.* p. 355.

[4] *Geol. Mag.* (1893), p. 546; *Q. J. G. S.* l. (1894), p. 311.

[5] *Amer. Journ. Sci.* iii. (1897), p. 21. Professor Brögger has replied to this criticism that we have no reason to believe the internal magma to be as viscous as Vesuvian lava. He points to the general absence of differentiation in superficial eruptive rocks and its frequent presence in deep-seated masses, and he argues that so long as the magma retains the enormous volume of aqueous and other vapours with which it is charged, it must possess great internal mobility, 'Das Ganggefolge des Laurdalits,' p. 336.

circulation will be established. If the lava be supposed to be a homogenous mixture of two liquids of different fusibility, the crusts which first form upon the walls will have nearly the same composition as the less fusible partial magma. The abstraction of the less fusible constituents will alter the composition of the circulating liquid, which will continually tend towards the composition of the most fusible mixture of the component ingredients. When this composition is attained the magma will no longer undergo change by circulation and partial solidification; and the residual mass will gradually solidify as a uniform material.[1] This is undoubtedly an important suggestion, though it may, perhaps, not be of wide application. Professor Brögger has pointed out that it requires that the least fusible materials should collect along the margins, whereas the contrary is, for the most part, the rule. This is, at least, the case in large masses, though in dykes, where the molten material has been rapidly chilled against walls of cold rock, the salband or marginal selvage is often less fusible and more acid than the centre.

From this necessarily brief and incomplete summary of published opinions it will be seen that the problem of the cause of the differentiation of igneous rocks, whether within the magma reservoirs or in extruded masses, is one of extreme complexity, the solution of which has not yet been reached. There seems to be no doubt that at least in regard to bosses, sills, and dykes, the variation has been to a considerable degree influenced by cooling, though it is less easy to conceive how this influence could have seriously affected the composition of the great magma reservoirs which certainly underwent a marked change during the course of a volcanic cycle. It may be, as Brögger has said, that the process was connected in the most intimate way with the crystallization of the molten material, and that certain analogies may be traced between the succession of changes involved in the processes of crystallization, differentiation and eruption.[2] The subject of the crystallization of rocks has been already referred to in this volume (pp. 302, 403-415), and the important researches of Elie de Beaumont, Daubrée, Fouqué, Michel-Lévy and others have been cited. But some further allusion to the question is required here, more particularly in regard to the order of appearance of the constituent minerals of eruptive rocks, and the possible connection of this order with the processes of differentiation and eruption discussed in the foregoing pages.

Crystallization of Eruptive Rocks.[3]—The experiments of Messrs.

[1] *Amer. Journ. Sci.* iii. (1897), p. 257.

[2] *Op. cit.* p. 364. Out of the voluminous literature which during the last dozen of years has gathered round this subject, it is only possible to find room here for some of the more important contributions. Besides the works of Teall, Harker, Sollas, Brögger, Iddings, Michel-Lévy, Becker, Hague, Spurr and others already cited, the following memoirs are worthy of special notice: L. V. Pirsson in *20th Ann. Rep. U. S. Geol. Surv.* Part iii. p. 569; Weed and Pirsson, *B. U. S. G. S.* No. 139, 1896; H. S. Washington, various papers in *Journ. Geol.* iv. v. vi. vii. and ix., and *Bull. Geol. Soc. Amer.* xi. (1900), p. 389; J. H. L. Vogt, *Geol. Fören. Stockholm*, xiii. (1891), p. 476; *Compt. rend. Congrès. Geol. Internat.* Zurich, 1894, p. 382; *Zeitsch. Prakt. Geol.* 1894, p. 381; 1895, pp. 145, 367, 444, 465; 1900, p. 233; 1901, pp. 9, 180, 289, 327—a remarkable series of researches regarding the separation of iron-ores in eruptive rocks, and its bearing upon the processes of magmatic differentiation.

[3] See the excellent summary by Professor Iddings, *Bull. Phil. Soc. Washington*, xi.

Fouqué and Michel-Lévy demonstrated that many minerals and rocks could be reproduced artificially by dry fusion, and that crystalline groupings and structures could be obtained precisely similar to those that occur in nature. The researches of Daubrée showed that at high temperatures and pressures water contributes powerfully to the solution of various mineral substances and to the production of new minerals and rock-structures, though neither he nor his French colleagues could succeed in reproducing granitic rocks by any method they could devise. In recent years this synthetic research has been prosecuted on a much larger scale, and with eminent success, by Professor Morozewicz, to whose work allusion has above been made (p. 406). We have seen that he has succeeded in obtaining, from mixtures of their chemical ingredients, a large suite of minerals and a number of rocks, including rhyolite and various basalts and andesites. But his researches have some important bearings on the consolidation and crystallization of eruptive rocks as a whole. His experiments have brought out with clearness the already known fact that the presence of alumina tends to retard the crystallization of an alkaline silicate magma. He has found that when alumina is added above the point of saturation to such a magma, its presence promotes the separation of aluminous silicates. He experimented with mixtures having the chemical composition of rhyolite and also of basalt, and obtained products in which the structure and order of appearance of the minerals were similar to those of these rocks in nature. He found that the minerals always crystallized in the same order, which is a constant function of the chemical composition of the magma, but his experiments led him to the conclusion that this order is not governed by any one condition alone, such as fusibility, acidity, or basicity, but is the result of several contributing causes, among which one of the most important is the relation between the quantities of the several compounds in the solution. Where the proportion of one of these compounds in any magma is large, the mineral will crystallize sooner than where it is small, and, as already pointed out, temperature comes also into play, some minerals making their appearance most readily at lower temperatures than those at which they can still be formed.[1]

Under certain conditions, more especially in veins of a particular kind, two mineral constituents of an igneous rock have crystallized simultaneously, and are mutually enclosed, one within the other. This structure is most familiarly displayed in graphic granite (pp. 128, 206, and Fig. 30), and in the coarse-grained veins which are known as pegmatites, where the graphic structure is not always developed.[2] More usually the

(1889), pp. 65-113. The student should consult the series of papers by Morozewicz, cited below; by Vogt, *Zeitsch. Prakt. Geol.* Nos. 1, 4, and 7, 1893; by Lagorio, *Zeitsch. f. Krystallog.* xxiv. (1895) p. 285; and the suggestive Presidential Address by Mr. Teall, *Q. J. G. S.* lvii. (1901), p. 62.

[1] Professor Morozewicz's papers are contained in *Neues Jahrb.* 1893, ii. p. 43; *Zeitsch. f. Krystallog.* xxiv. (1895), p. 281; *Tschermak's Mitth.* xviii. (1898), pp. 1-90, 105-240. There is a good summary of them by Mr. Jaggar in *Journ. Geol.* vii. (1899), pp. 300-313.

[2] See on this subject the remarks of Professor Brögger in his "Mineralien der Syenitpeg-

several minerals separated out successively, but the order of their appearance is not invariable, and we are still far from comprehending the conditions that determine the normal order and those that lead to deviations from it. The supposition obviously suggests itself that minerals will crystallize out of a magma in the order of their respective fusibilities, those with the highest fusion-points separating out first. But experience shows that such is not strictly the case. Rosenbusch has remarked that their appearance is in the order of decreasing basicity, ores coming first, followed by ferro-magnesian minerals, felspathic minerals, and lastly by quartz. But there are some important exceptions to this general rule. In granite the difficultly fusible quartz is often found moulded round the more fusible felspar, and in dolerites the pyroxenes may not infrequently be seen ophitically enclosed within the felspars. The opinion has long prevailed that in these cases the presence of water or some other "mineralising agent" plays an important part. It has been proved experimentally that in presence of water anhydrous silica can be made fluid at a temperature of 300° C., which is far below its fusion-point.[1] Professor Joly has recently called attention to the importance of discriminating between the fusion-point and the viscosity of minerals at high temperatures. He has found that silica is a body possessing a remarkable range of viscosity. Its fusion-point is stated to be 1406° C.; at 1500° C. it is a very thick liquid, but about 800° C. it becomes plastic and yields with considerable rapidity to distorting forces. The question of time has been found to be important in determining the fusibility of substances. When rapidly fused their fusion-points may vary considerably. Thus leucite melts at 1030° and augite at 1140° when time has been allowed for the development of their viscosity. But when rapidly heated to 1300° the fluidity of leucite is the same as that of augite at 1200°, and much more complete than that which they present at 1030° and 1140°. At a temperature of say 1280°, leucite exists in a very viscous condition below its normal point of fusion (which is about 1300°); augite, on the other hand, remains quite fluid, because it is 80° above its normal point of fusion. Hence in the cooling of a magma from such a temperature, the leucite can begin to crystallise and the crystals to develop before the augite has formed any crystals, or at most has passed beyond the microlitic condition.[2]

If we regard a molten magma as a solution in which all its chemical constituents are completely dissolved, the chief condition that must determine the separation of these constituents is probably a sinking of the temperature. As the mass cools the ingredient which soonest

matitgänge," Part i. p. 148 *et seq.* He describes examples of the simultaneous crystallization of felspar with diopside, with lepidomelane, with hornblende, and with pyroxene.

[1] Professor Sollas, *Geol. Mag.* 1900, p. 295. Professor Joly has melted quartz by igneous fusion at a temperature of 1200° C. during eighteen hours, and has obtained from it crystalline forms when cooled down to 915° C.

[2] Joly, *Sci. Proc. Roy. Dublin Soc.* ix. (1900), p. 298; *Congrès Géol. Internat.* Paris, 1900, p. 691. Doelter has lately determined the fusibility of some minerals ranging from 920° (melanite) to 1400° (bronzite). He finds the Predazzo granite to soften at 1150° and to fuse at 1240°. *Tschermak. Mitt.*, 1902, p. 23.

reaches its point of saturation will usually crystallize first, and the successive appearance of the minerals will continue until the whole magma has crystallized, or until the remaining non-devitrified glass becomes solid. During this process a complex series of chemical changes is in progress. The early separation of the more basic constituents leaves the composition of the whole mass more acid; further reactions are set on foot which may ultimately advance even to the reabsorption of minerals already crystallized. Among these changes the same mineral may make its appearance more than once during the crystallization of a magma. Felspars, for instance, frequently appear in eruptive rocks as the products of a first and of a second consolidation. Porphyritic crystals or phenocrysts, which are dispersed through a fine-grained ground mass full of smaller, sometimes microlitic, forms of the same mineral, are regarded as evidence of this succession.[1]

The crystallization of an intrusive igneous mass must no doubt be more or less modified by the conditions of depth, temperature, movement, and other causes that affect the bodies of molten material which are protruded into the terrestrial crust. Dr. Weinschenk has especially dwelt upon this influence as a determining factor in the production of the structure of the central granite of the Alps. He believes that rock to have been part of a normal granitic magma which crystallized under abnormal conditions, and that it owes its mineralogical composition and characteristic foliated structure, not to any process of subsequent dynamometamorphism, but to the peculiar relations of tension accompanying the plication of the mountains. To these relations he has given the name of "piezocrystallization"—a term by which he understands an entirely primary formation of massive rocks, wherein, besides the high tension allowed for the crystallization of a normal deep-seated mass, we must also reckon the compression due to orographic movements during the consolidation of the rock.[2]

Many rocks in consolidating from the condition of glass have taken a spherulitic structure (pp. 131, 152), where crystalline intergrowths of two or more minerals have started from numerous centres, and have developed the characteristic internal radiating fibrous arrangement and usually globular external form. The conditions that have determined this type of devitrification are not well understood. Mr. Whitman Cross has suggested that in acid glasses there has first been a globular aggregation of colloid silica, in which the felspar substance is enclosed and becomes simultaneously individualised.[3] Professor Iddings, from a study of the remarkably fresh varieties of acid lavas found in the Yellowstone Park, in many of which the spherulites are hollow (lithophyses) and of large size, came to the conclusion that the differences in consistency and in the phases of crystallization, producing the lamination and spherulitic structure of these rocks, were directly due to the amount of vapours

[1] See, however, the observations of L. V. Pirsson, *Amer. Journ. Sci.* vii. (1899), p. 271, and W. O. Crosby, *Amer. Geol.* xxv. (1900), p. 299.

[2] E. Weinschenk, "Beiträge zur Petrographie der Östlichen Centralalpen," *Abhandl. Bayer. Akad.* xviii. (1894), p. 91.

[3] *Bull. Phil. Soc. Washington*, xi. (1891), p. 436.

absorbed in the various layers of the lava, and to their mineralising influence; the lithophyses being thus of aqueo-igneous origin, due to the action of the absorbed gases upon the molten glass from which they were liberated during the crystallization consequent upon cooling.[1]

Classification of Eruptive Rocks according to their Tectonic Relations.—In dealing with the occurrence of igneous rocks as part of the architecture of the earth's crust, we require some principle of grouping which will enable us to arrange their various structures in such a manner as will best convey an idea of the relation which they bear to the rest of the crust, and of the light which they can be made to throw upon the behaviour of the molten materials of the planet, whether beneath or above the surface. Keeping in view a useful distinction already mentioned, we may group together all subterranean intruded masses, now revealed at the surface after the removal of some depth of overlying rock, as one division under the names Plutonic, Intrusive, or Subsequent. On the other hand, we may class all those which came up to the surface as ordinary volcanic rocks, whether molten or fragmental, and were consequently contemporaneously interstratified with the formations which happened to be in progress on the surface at the time, as a second group under the names Volcanic, Interstratified, or Contemporaneous.

It is obvious that these can be used only as relative terms. Every truly volcanic mass which, by being poured out as a lava-stream at the surface, came to be regularly interstratified with contemporaneous accumulations, must have been directly connected below with molten matter which did not reach the surface. One part of the total mass, therefore, would be included in the second group, while another portion, if ever exposed by geological revolutions, would be classed with the first group. Seldom, however, can the same masses which flowed out at the surface be traced directly to their original underground prolongations.

Fig. 296.—Section showing the relative age of an Intrusive Rock (B.

It is evident that an Intrusive mass, though necessarily subsequent in age to the rocks through which it has been thrust, need not be long subsequent. Its relative date can only be certainly affirmed with reference to the rocks through which it has broken. It must obviously be younger than these, even though they lie upon it, if they bear evidence of alteration by its influence. The probable geological date of its eruption must be decided by evidence to be obtained from the grouping of the rocks all around. Its intrusive character can only certainly determine the limit of its antiquity. We know that it must be younger than the rocks it has invaded; how much younger, must be otherwise determined. Thus, a mass of granite or a series of granite veins (*a a*, Fig. 296) is

[1] *Amer. Journ. Sci.* xxxiii. (1887), pp. 42, 45. See *ante*, pp. 406, 414, where the artificial production of the spherulitic structure by Morozewicz and Daubrée is referred to.

manifestly posterior in date to the plicated rocks (*b b*) through which it has risen. But it must be regarded as older than overlying undisturbed and unaltered rocks (*c*), or than others lying at some distance (*e f*), which contain worn fragments derived from the granite.

On the other hand, an Interstratified or Contemporaneous igneous rock has its date precisely fixed by the geological horizon on which it lies. Sheets of lava or tuff interposed between strata in which such fossils as *Calymene Blumenbachii*, *Leptæna sericea*, *Atrypa reticularis*, *Orthis elegantula*, and *Pentamerus Knightii* occur, would be unhesitatingly assigned by a geologist to submarine volcanic eruptions of Upper Silurian age. A lava-bed or tuff intercalated among strata containing *Calymmatotheca affinis*, *Lepidodendron veltheimianum*, *Leperditia*, and other associated fossils, would unequivocally prove the existence of volcanic action at the surface during the Lower Carboniferous period, and at that particular part of the period represented by the horizon of the volcanic bed. Similar eruptive material associated with *Ammonites*, *Belemnites*, *Pentacrinites*, &c., would certainly belong to some zone in the great Mesozoic suite of formations. An interbedded and an intrusive mass found on the same platform of strata need not necessarily be coeval. On the contrary, the latter, if clearly intruded along the horizon of the former, would obviously be posterior in date. It will be understood, then, that the two groups have their respective limits determined mainly by their relations to the rocks among which they may happen to lie, though there are also special internal characters that help to discriminate them.

The value of this classification for geological purposes is great. It enables the geologist to place and consider by themselves the granites, quartz-porphyries, and other crystalline masses, which, though lying sometimes perhaps at the roots of ancient volcanoes, and therefore, in that case, intimately connected with volcanic action, yet owe their special characters to their having consolidated under pressure at some depth within the earth's crust; and to arrange in another series the lavas and tuffs which, having been thrown out to the surface, bear the closest resemblance to the ejected materials from modern volcanoes. He is thus presented with the records of hypogene igneous action in the one group, and with those of superficial volcanic action in the other. He is furnished with a method of chronologically arranging the volcanic phenomena of past ages, and is thereby enabled to collect materials for a history of volcanic action over the globe.

In adopting this classification for unravelling the geological structure of a region where igneous rocks abound, the student will encounter instances where it may be difficult or impossible to decide in which group a particular mass of rock must be placed. He will bear in mind, however, that, after all, such schemes of classification are proposed only for convenience in systematic work, and that there are no corresponding hard and fast lines in nature. He will recognise that all crystalline or glassy igneous rocks must be intrusive at a greater or less depth from the surface; for every contemporaneous sheet has obviously proceeded from some internal pipe or mass, so that, though interbedded and contem

poraneous with the strata at the top, it is intrusive in relation to the strata below.

The characters by which an eruptive rock may be distinguished are partly lithological and partly geotectonic. The lithological characters have already been fully given (pp. 195-243). Among the more important of them are the predominance of silicates (notably of felspars, hornblende, mica, augite, olivine, &c.), and of disseminated crystals of iron oxides (magnetite, titaniferous iron); a prevailing more or less thoroughly crystalline structure; the frequent presence of vitreous and devitrified matter, visible megascopically or microscopically; and the occurrence of porphyritic, cellular, pumiceous, slaggy, amygdaloidal, and fluxion structures. These characters are never all united in the same rock. They possess likewise various values as marks of eruptivity, some of them being shared with crystalline schists which, as schists, were certainly not eruptive. On the whole, the most trustworthy lithological evidence of the eruptive character of a rock is the presence of glass, or traces of an original glassy base. We do not yet certainly know of any natural glass, except of an eruptive origin. The occurrence or association of certain minerals, or varieties of minerals, in a rock, may also afford presumptive evidence of its igneous origin. Sanidine, leucite, olivine, nepheline, for example, are, for the most part, characteristic volcanic minerals; and mixtures of finely crystallized triclinic felspars with dark augite, olivine, and magnetic iron, or with hornblende, are specially met with among eruptive rocks.

But it is the geotectonic characters on which the geologist must chiefly rely in establishing the eruptive nature of rocks. These vary according to the conditions under which the rocks have consolidated. We shall consider them as they are displayed by the Plutonic, or deep seated, and Volcanic, or superficial phase of eruptivity.[1]

Section i. Plutonic, Intrusive, or Subsequent Phase of Eruptivity.

We have here to consider the structure of those eruptive masses which have been injected or intruded into other rocks, and have consolidated beneath the surface. One series of these masses is crystalline in structure, but with felsitic and vitreous varieties. It includes examples of most of the eruptive rocks, and especially of the more coarsely crystalline forms (granite, syenite, quartz-porphyry, granophyre, rhyolite, diorite, gabbro, &c.). The other series is fragmental in character, and includes the agglomerates and tuffs which have filled up volcanic orifices.

After some practice, the field-geologist acquires a faculty of discriminating with more or less confidence, even in hand-specimens, crystalline rocks which have consolidated beneath the surface, from

[1] As already stated (p. 198), a chronological basis has been proposed among the other plans for the classification of eruptive rocks. Some writers have even gone so far as to suggest that different names should be given to eruptive rocks according to the geological formation in which they occur, as *Carbophyre, Kohlephyre, Triaphyre, Juraphyre.* See Th. Ebray, *B. S. G. F.* (3), iii. p. 291.

those which have flowed out as lava-streams. Coarsely crystalline granites and syenites, with no trace of any vitreous ground-mass, are readily distinguishable as plutonic masses; while, on the other hand, cellular or slaggy lavas are easily recognisable as superficial outflows, or as closely connected with them. But it will be observed that such differences of texture, though furnishing useful helps, are not to be regarded as always and in all degrees perfectly reliable. We find, for example, that some lavas have appeared at or near the surface with so coarsely crystalline a structure as to be mistaken by a casual observer for granite; while, on the other hand, though an open pumiceous or slaggy structure is certainly indicative of a lava that has consolidated at or near the surface, a finely cellular character is not wholly unknown in intrusive sheets and dykes which have consolidated below ground. Again, masses of fragmentary volcanic material are justly regarded as proofs of the superficial manifestation of volcanism, and in the vast majority of cases, they occur in beds which were accumulated on the surface, as the result of successive explosions. Yet cases (described at p. 748) may be found in many old volcanic districts, where such fragmentary materials, falling back into the volcanic funnels, and filling them up, have been compacted there into solid rock. On rare occasions, explosions of lava within subterranean caverns may have given rise to such accumulations of agglomerate.

The general law which has governed the intrusion of igneous rock within the earth's crust may be thus stated: Every fluid mass impelled upwards by pressure from below, or by the expansion of its own imprisoned vapour, has sought egress along the line of least resistance. That line has depended in each case upon the structure of the terrestrial crust and the energy of eruption. It may have been determined by an already existent dislocation, by planes of stratification, by the surface of junction of two unconformable formations, by contemporaneously formed cracks, or by other more complex lines of weakness. Sometimes the intruded mass has actually fused and obliterated some of the rock which it has invaded, incorporating a portion into its own substance. The shape of the channel of escape has determined the external form of the intrusive mass, as a mould regulates the form assumed by cast-iron. This relation offers a very convenient means of classifying intrusive rocks. According to the shape of the mould in which they have solidified, they may be arranged as—(1) bosses or amorphous masses, (2) sills or sheets, (3) veins and dykes, and (4) necks.

§ 1. Bosses.

Bosses (stocks) are amorphous masses that have disrupted the rocks through which they rise. They consist chiefly of crystalline, coarse-textured rocks such as granite and syenite, but include also quartz-porphyries, felsites, trachytes, diorites, gabbros, diabases, andesites, dolerites, &c. Where rocks assume this form as well as that of sheets, dykes, and contemporaneous beds, it is commonly observed that they

are more coarsely crystalline when in large amorphous masses than in any other form. Pyroxenic rocks afford many examples of this characteristic. In the basin of the Forth, for instance, while the outflows at the surface have been fine-grained basalts, the masses consolidated underneath have generally been coarse dolerites or diabases.[1]

It has already been pointed out that in the consolidation of an igneous rock, the more basic minerals have generally crystallized out first, and that the last portions of the mass to solidify have not infrequently a notably more acid character than those which solidified first. Hence the margin of an eruptive mass may show a more basic composition than the central portions which cooled more slowly. As we have seen, a remarkable range of composition may thus be found within the same boss.[2] Again, if during the process of consolidation an intrusive mass should be ruptured and portions of the still liquid matter be forced into the rents, these veins or squirts will generally be found to be decidedly more acid than the rock in which they lie.

Granite.—It was once a firmly-held tenet that granite is the oldest of rocks, the foundation on which all other rocks have been laid down. This idea no doubt originated in the fact that granite is found rising from beneath gneiss, schist, and other crystalline masses, which in their turn underlie very old stratified formations. The intrusive character of granite, shown by its numerous ramifying veins, proved it to be later than at least those rocks which it had invaded. Nevertheless, the composition and structure of gneiss and mica-schist were believed to be best explained by supposing these rocks to have been derived from the waste of granite, and thus, though the existing intrusive granite had to be recognised as posterior in date, it was regarded as only a subsequent protrusion of the vast underlying granitic crust. In this way, the idea of the primeval or fundamental nature of granite held its ground. From what is known regarding the fusion and consolidation of rocks (*ante*, p. 402 *et seq.*), and from the evidence supplied by the microscopic structure of granite itself (p. 144), this rock may be regarded as having generally consolidated under great pressure, in presence of superheated water, with or without liquid carbon-dioxide, fluorine, &c., conditions which probably never obtained at the earth's immediate surface, unless, perhaps, in those earliest ages when the atmosphere was densely loaded with vapours, and when the atmospheric pressure at the surface was great (p. 44). Whether the original crust was of a granitic or of a glassy character, no indubitable trace of it has ever been or is ever likely to be found. There can be no doubt, however, that the oldest known rocks are either granites, or granitoid gneisses which have probably been formed out of granite.

The presence of granite at the existing surface is, doubtless, in all cases due to the removal by denudation of masses of rock under which it originally consolidated. The fact that, wherever extensive denudation of an ancient series of crystalline rocks has taken place, a subjacent granitic nucleus is apt to appear, does not prove granite to be of primeval origin.

[1] Bosses may not infrequently be laccolites laid bare by denudation, but without exposure of their foundations; *postea*, p. 736. [2] See pp. 710-712, and authorities there cited.

It shows, however, that the lower portions of crystalline rocks very generally assume a granitic type, and it suggests that if, at any part of the earth, we could bore deep enough into the crust, we should probably come to a granitic layer. That this layer, even if general round the globe, is not everywhere of the highest geological antiquity, or at least has consolidated at widely different periods, is abundantly clear from the fact that in many cases it can be proved to be of later date than fossiliferous formations the geological position of which is known; that is, the granitic layer has invaded these formations, rising up through them, and possibly melting down portions of them in its progress. Granite invades and alters rocks of all ages up to late Mesozoic and Tertiary formations. Hence, it does not belong exclusively to the earliest nor to any one geological period, but has rather been extruded at various epochs, and may even be in course of extravasation now, wherever the conditions required for its production still exist. As a matter of fact, granite occurs much more frequently in association with older, and therefore lower, than with newer and higher rocks. But a little reflection shows that this ought to be the case. Granite, having a deep-seated origin, must rise through the lower and more ancient masses before it can reach the overlying more recent formations. But many protrusions of granite would, doubtless, never ascend beyond the lower rocks. Subsequent denudation would be needed to reveal these protrusions, and this very process would remove the later formations, and, at the same time, any portions of the granite which might have reached them.

Granite frequently occurs in the central parts of mountain chains; sometimes it forms there a kind of core to the various gneisses, schists, and other crystalline rocks. It appears in large eruptive bosses, which traverse indifferently the rocks on the line of which they rise, and commonly send out abundant veins into them. Sometimes it even overlies schistose and other rocks, as in the Piz de Graves in the upper Engadine, where a wall-like mass of granite, with syenite, diorite, and altered rocks, may be seen resting upon schists.[1] In the Alps and other mountain ranges, it is found likewise in large bed-like masses which run in the same general direction as the rocks with which they are associated.[2]

Reference has already been made (p. 204) to some of the more marked varieties of texture and structure in granite bosses. To a few of these further and more detailed remarks may be appropriately inserted here. The patches or enclosures in granite, which differ in colour, texture, and composition from the general mass of the rock, may be grouped in two divisions: 1st, Angular or subangular fragments, probably in most cases derived from the rocks through which the granite has been protruded. These are sometimes tolerably abundant towards the outer margin of a

[1] Studer, 'Geologie der Schweiz,' i. p. 290.

[2] On the granite of the Alps, see Michel-Lévy, *Bull. Carte. Géol. France*, No. 9, 1890, No. 36, 1893; Duparc et Mrazek, *Mém. Soc. Phys. Hist. Nat. Genève*, xxxiii. No. 1 (1898); D. Stur, *Verh. k. k. Geol. Reichsanst*, v. (1854), p. 818; C. Schmidt, *Beitr. Geol. Karte. Schweiz.* Liefer. xxi. (1891); E. Weinschenk, *Abhandl. Bayer. Akad.* ii class. xviii. (1894), p. 67.

boss. They usually show considerable contact-metamorphism, due no doubt to the influence of the eruptive rock in which they are enclosed. 2nd, Globular or rounded concretions, due to some process of segregation and crystallization, in the original still unconsolidated granite. Examples of this nature occur in the Cornish and Devon granite, as in Fig. 297, which was long ago cited by De la Beche as showing a central cavity (*a*), not quite filled with long crystals of schorl surrounded with an envelope of quartz and schorl (*b*), outside of which lies a second envelope (*c*) of the same minerals, the schorl predominating, the whole being contained in a light flesh-coloured and markedly felspathic granite (*d*). But more remarkable concretionary forms have since been observed in many granites, some of them presenting an internal radial concentric arrangement, and recalling the orbicular structure of some diorites (Napoleonite) (Fig. 8). Such concretionary aggregations are generally more basic than the surrounding granite.[1]

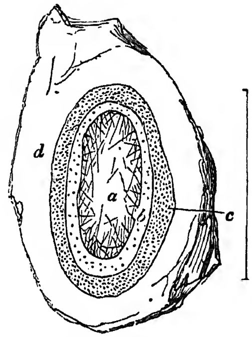

Fig. 297.—Crystalline geode in granite, Dartmoor (*B.*).

Of more importance, as affecting a much larger proportion of a granite boss, are the differences of texture and of structure not infrequently traceable from the margin to the centre. Like most intrusive rocks, granite is apt to be more close-grained at its contact with the surrounding strata than in the centre of its mass, though it does not show this contrast so strikingly as the more basic rocks, such as gabbro, diabase, and dolerite, probably because it was injected at depths where the surrounding rocks were hot, whereas the basic rocks visible at the surface were, for the most part, erupted among cool rocks, where along the contact the igneous masses were rapidly chilled. Certain characteristic varieties of texture and even to some extent of composition may be recognised in many granite areas. In particular the marginal portions not infrequently present a foliated arrangement which simulates the structure of gneiss, the folia being rudely parallel to the margin of contact and either vertical or dipping at high angles away from the core of granite. It has been already stated that in some granite bosses a striking gradation can be traced even into picrites and serpentines.

A detailed study has been made by Professor Charles Barrois of the granulites (*i.e.* granites with two micas) of the Morbihan in Brittany. He has shown that the large bosses, measuring some hundreds of square kilometres, present certain well-marked modifications not only of structure but of composition, as they are traced from the centre to the periphery, while the smaller bosses show no such modifications and are to be regarded merely as apophyses from those of large size. The modifications along the contact do not arise from any exchange of substance between the granite and the surrounding rock, but solely from the influence of cooling which has affected the orientation of the minerals, their grouping and their order of crystallization. Where the

[1] See the papers on orbicular granite cited on p. 206, also Harker and Marr, *Q. J. G. S.* xlvii. (1891), p. 280.

granite has risen parallel to the strike of the adjacent strata, it usually passes from its ordinary granular into a porphyroid structure, with its large constituents arranged parallel as in flow-structure ; where, on the other hand, it breaks across the bedding, it has assumed a finely granular massive character (aplite) with its crystalline constituents showing regular geometric forms. These variations are thus proved, in this particular instance, to depend on the influence of the surrounding envelope, which though chemically inactive, offers considerable diversity as a conductor of heat and of pressure. The crystallization of the constituents of the rock took place progressively from the outside inwards, that is, from a mass still in motion across a magma that had come to rest and which shows now no trace of flow. But besides this marginal band of "porphyroid granulite," the external portions of the southern flanks of the bosses present a remarkable schistose structure which, likewise limited to a peripheral zone, resembles that of gneiss, both fine-grained and glandular (augen-gneiss). Examined in detail the mica-flakes of this gneissic band are found to be torn and drawn out, the felspar crystals deformed, broken, and blunted, indicating the powerful mechanical forces which have affected the rock. These crushed constituents have subsequently been re-cemented by membranes and fibres of white sericitic mica, sometimes of black mica, and by sheets of secondary granular quartz, formed out of the triturated débris of the older ingredients. Considering the gradual passage of these schistose selvages into the ordinary granular rock, and the further fact that the schistose structure occurs only on the southern flanks of the granitic bosses of the Morbihan, Dr. Barrois attributes this structure to a powerful lateral pressure which has acted in a direction from south to north.[1]

Relation of Granite to contiguous Rocks.—From an early period the attention of geologists has been given to the evident mineralogical change which has taken place among stratified rocks as they approach a mass of granite. This change is developed within a ring or areola (Fig. 300) which encircles the granite, and varies in breadth from a few yards to two or three miles. The most intense alteration is found next the granite, while along the outer margin of the areola the normal character of the rocks is resumed. In some cases, however, no perceptible trace of alteration can be detected next a mass of granite. Of the European examples of contact-metamorphism, those of Devon and Cornwall, Ireland, Scotland, the Harz, Vosges, Pyrenees, and Norway have long been known. Instructive illustrations of the same features have been found all over the world. The nature of the metamorphism thus superinduced upon rocks is more particularly discussed at pp. 778-783.

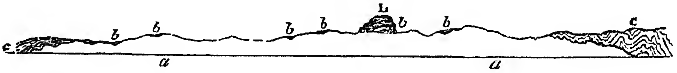

Fig. 298.—Section across part of the granite belt of the south-east of Ireland.
a, Granite ; *b b*, patches of Lower Silurian rocks lying on the granite at various distances from the main Lower Silurian area, *c c*.

The south-east of Ireland supplies an admirable illustration of the relation between granite and its surrounding rocks (Fig. 298). A mass of granite 70 miles in length and from 7 to 17 in width stretches there from north-east to south-west, nearly along the strike of the Lower Silurian rocks. These strata, however, have not been upraised by it in such a way as to expose their lowest beds dipping away from the granite. On the contrary, they seem to have been contorted prior to the appearance of that rock ; at

[1] *Ann. Soc. Géol. Nord.* xv. (1887), pp. 1-40.

least they often dip towards it, or lie horizontally or undulate upon it, apparently without any reference to movements which it could have produced. As Jukes showed, the Silurian strata are underlain by a vast mass of Cambrian rocks, all of which must have been invaded by the granite before it could have reached its present position. He infers that the granite must have slowly and irregularly eaten its way upward through the Silurian rocks, absorbing much of them into its own mass as it rose. For a mile or more, the stratified beds next the granite have been altered into mica-schist, and are pierced by numerous veins from the invading rock. Within the margin of the granitic mass, belts or rounded irregular patches of schist (*b b*) are enclosed; but in the central tracts, where the granite is widest, and where therefore we may suppose the deepest parts of the mass have been laid bare, no such included patches of altered rock occur. From the manner in which the schistose belt is disposed round the granite, it is evident that the upper surface of the latter rock, where it extends beneath the schists, must be very uneven. Doubtless the granite rises in some places much nearer to the present surface of the ground than at others, and sends out veins and strings which do not appear above ground. If, as Jukes supposed, a thousand feet of the schists could be restored at some parts of the granite belt, no doubt the belt would there be entirely buried; or if, on the other hand, the same thickness of rock could be stripped off some parts of the band of schist, the solid granite underneath would be laid bare. The extent of granite surface exposed must thus be largely determined by the amount of denudation, and by the angle at which the upper surface of the granite is inclined beneath the schists. Where the inclination is high, prolonged denudation will evidently do comparatively little in widening the belt.[1] But where the slope is gentle, and especially where the surface undulates, the removal, for some distance, of a comparatively slight thickness of rock, may uncover a large breadth of underlying granite. Portions of the metamorphosed rocks left by denudation upon the surface of the granite boss, are relics of the deep cover under which the granite no doubt originally lay, and, being tougher than the latter rock, they have resisted waste so as now to cap hills and protect the granite below, as at the mountain Lugnaquilla (L in Fig. 298), which rises 3039 feet above the sea.

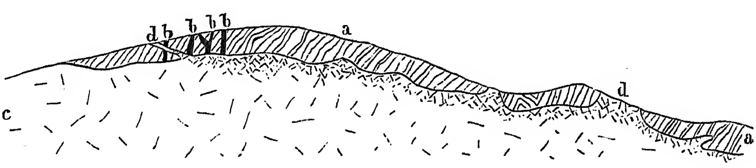

Fig. 299.—Section of Slievenamaddy, Mourne Mountains.

a a, Lower Silurian strata dipping at high angles; b b, Dykes of basalt (melaphyre), cutting these strata but truncated by the granite *c*, which along the outer margin and in extruded veins passes into a quartz-porphyry, *d d*.

Observations by Professor Hull and Mr. Traill, have shown that in the Mourne Mountains, a mass of (probably Tertiary) granite has in some parts risen up through highly inclined Silurian rocks, which consequently seem to be standing almost upright upon an underlying boss of granite. The strata are sharply truncated by the crystalline mass, and are indurated but not otherwise altered. The intrusive nature of the granite is well shown by the way in which numerous dykes of dark melaphyre are cut off when they reach that rock.[2] The accompanying diagram (Fig. 299) is taken from one of the sections in which this structure is portrayed by these observers.

[1] See Jukes's 'Manual of Geology,' 3rd ed. p. 243.

[2] Horizontal Section No. 22, Geol. Surv. Ireland.

In the Lower Silurian tract of the south of Scotland several large intrusive bosses of granite occur (Fig. 300). The strata do not dip away from them on all sides, but with trifling exceptions maintain their normal N.E. and S.W. strike up to the granite on one side, and resume it again on the other. The granite indeed has not merely pushed aside the strata so as to make its way past them, but actually occupies the place of so much Silurian greywacke and shale, which have disappeared, as if they had been pushed or blown out, or had been melted up into the granite. There is usually a metamorphosed belt of about a mile in width, in which, as they approach the granite, the stratified rocks assume a thoroughly schistose character. Numerous small, dark, often angular patches or fragments of mica-schist may be observed in the marginal parts of the granite. Occasionally granite-veins protrude from the main masses; in the metamorphosed zone which surrounds the Criffel granite area in Kirkcudbright, hundreds of dykes and veins of various felsitic or elvanitic rocks occur (see p. 739).[1]

Similar features are presented by the granite bosses of Devon and Cornwall, which have risen through Devonian and Carboniferous strata. The Dartmoor mass is specially instructive. As shown by the early work of De la Beche, it passes across the boundary between the Devonian and Carboniferous areas, extending chiefly into the latter, so that it cuts across strata of different ages. In doing so it has risen irresistibly through the crust, without seriously affecting the general strike of the rocks. It cuts volcanic bands, as well as grits and shales, into which it sends veins.[2]

A striking feature along the marginal parts of some granites is the extent to which they have absorbed or incorporated the material of the rock through which they have risen. In some cases all that can be recognised of the sedimentary rocks thus attacked is in shreds, patches, and streaks imbedded in a paste of igneous origin. Such a paste is described by Mr. Teall as illustrated by a cordierite gneiss from Aberdeenshire, where the igneous constituents are represented by oligoclase, biotite, orthoclase, and quartz, while the sedimentary portion is indicated by cordierite, quartz, biotite, sillimanite, iron-ores, and a green spinel.[3] The process of absorption is perhaps best seen where the invaded rock is markedly basic, as where gabbro has been attacked by granophyre in the north-east of Ireland, the Lake district, and the north-west of Scotland, to which reference will be made on a later page (p. 776). So far as observation has yet gone, this incorporation of foreign material is mainly a peripheral phenomenon among intrusive rocks. How far it has ever been carried into the body of a great granite mass, so as appreciably to affect the structure and composition of the body of the rock, has not been ascertained.

Injection of Granite—Granitisation.—The permeation of different rocks by granitic material has been much studied in recent years. M. Michel-Lévy, who has devoted especial attention to the subject, believes that two types of this permeation may be recognised. In the one case the material has so absorbed the surrounding rocks that no line of demarcation can be drawn between them. In the second type the granitic magma has insinuated itself between the finest divisional planes of the schists, saturating them and forming alternate folia of schist and granite. This remarkable structure, termed by the distinguished French geologist *lit-par-lit* injection, was first described by him from examples which he had met with in France. He saw that so minute and

[1] Explanation of Sheets 5 and 9, Geological Survey of Scotland. The contact-metamorphism of these granite bosses is described *postea*, p. 779.

[2] De la Beche, 'Report, Devon and Cornwall,' p. 165. J. A. Phillips, *Q. J. G. S.* xxxiv. p. 493. Compare the action of the Tertiary granites of Skye, *Trans. Roy. Soc. Edin.* xxxv. (1888), Fig. 56, p. 170, and the papers of Harker and Sollas, cited *postea*, p. 776.

[3] Address, *Q. J. G. S.* lviii. (1902), p. lxxiv.

intimate was the interpenetration of the granitic material that the resulting aggregate became neither a true granite nor an ordinary schist. The quartz and felspar have crystallized between the planes of stratification, cleavage, or foliation so as to transform, for example, a clastic clay-slate into a rock which could only with difficulty be discriminated from ancient gneisses.[1] A similar structure is displayed in many parts of the Scottish Highlands. Messrs. Horne and Greenly have described an instructive example of it from Sutherland. They show that the whole mass of rock must have remained for a long time at a high temperature, for even where the granite sends sills and veins into the schists it never shows any sharp fine-grained or "chilled" edges, but seems to merge insensibly into the environing rock, through a series of thinner and thinner lenticles, or by a dovetailing with the biotitic folia of the gneiss. The granites themselves are likewise foliated, part of this structure being apparently due to the incorporation of the quartzo-felspathic elements of the schists into those of the granite, every gradation being traceable from inclusions that retain their natural orientation down to the merest trains of mica-flakes.[2]

In connection with this subject it may here be remarked that the close relationship between granite and the crystalline schists has long been recognised. It was formerly believed by many geologists that some granite is of metamorphic origin, that is to say, may have been produced by the gradual softening and recrystallization of other rocks at some depth within the crust of the earth. As gradations can be traced from gneiss through less distinctly crystalline schists into unaltered strata, the granite into which such gneiss seems to pass was looked upon as the extreme of metamorphism, the various schists and gneisses being less advanced stages of the process. Subsequent observation has shown that though granite must be regarded as properly an eruptive and not a metamorphic rock, yet that such a transformation alike of altered sediments and of the granite itself as are involved in *lit-par-lit* saturation, introduces us to a kind of double metamorphism, in view of which the old idea of metamorphic granite does not now appear so utterly contrary to nature.

Connection of Granite with Volcanic Rocks.—The manner in which some bosses of granite penetrate the terrestrial crust strongly recalls the structure of volcanic necks or pipes (p. 748). The granite is found as a circular or elliptical mass which seems to descend vertically through the surrounding rocks without seriously disturbing them, as if a tube-shaped opening had been blown out of the crust of the earth, up which the granite had risen. Several of the granite masses of the south of Scotland, above referred to, exhibit this character very strikingly (Fig. 300). That granite and granitoid rocks have probably been associated with volcanic action is indicated by the way in which they occur in connection with the Tertiary volcanic rocks of Skye, Mull, and other islands in the Inner Hebrides. Jukes suggested many years ago that granite or

[1] *B. S. G. S. F.* ix. (1881), p. 187; xvi. (1888), p. 221, "Sur l'origine des Terrains crystallins primitifs."

[2] *Q. J. G. S.* lii. (1896), p. 633.

granitoid masses may lie at the roots of volcanoes, and may be the source whence the more silicated lavas proceed.[1]

Bosses of other rocks than Granite.—On a smaller scale usually than granite, other crystalline rocks assume the condition of amorphous bosses. Diorite, syenite, quartz-porphyry, gabbro, and members of the diabase and basalt family have often been erupted in irregular masses, partly along fissures, partly along the bedding, but often involving and apparently melting up portions of the rocks through which they have made their way. Such bosses have frequently tortuous boundary-lines, since they send out veins into, or cut capriciously across, the surrounding rocks..

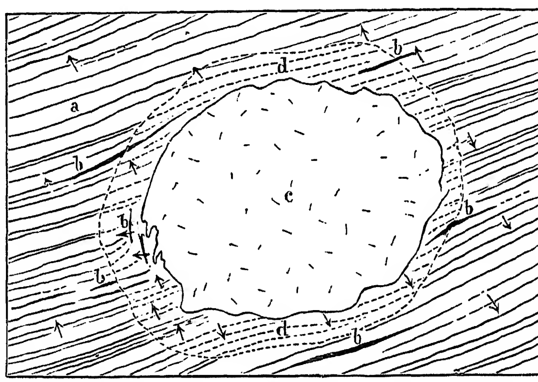

Fig. 300.—Plan of granite boss, Cairnsmore of Fleet, Scotland.

The granite area (*c*) is from 7 to 10 miles in diameter, rising through highly inclined Lower Silurian strata (*a*), among which are some conspicuous bands of black anthracitic and graptolitic shales (*b b*). The arrows show the direction of dip; the parallel lines that of the strike. The ring within the dotted line round the granite defines the areola of metamorphism.

In Wales, as shown by the maps and sections of the Geological Survey, the Lower Silurian formations are pierced by huge bosses of different crystalline rocks, mostly included under the old term "greenstone," which, after running for some way with the strike of the strata, turn round and break across it, or branch and traverse a considerable thickness of stratified rock. In Central Scotland, numerous masses of dolerite or diabase have been intruded among the Lower Carboniferous formations. One horizon on which they are particularly abundant lies about the base of the Carboniferous Limestone series. Along that horizon, they rise to the surface for many miles, sometimes ascending or descending in geological position, and breaking here and there abruptly across the strata.[2] Gaps occur where they do not appear at the surface, but as they resume their position again not far off, it may be presumed that they are really connected under these blank intervals. In the Inner Hebrides huge bosses of gabbro occur as well as granophyre and other acid rocks in the midst of the Tertiary volcanic series.

Effects on Contiguous Rocks.—The contact-metamorphism around bosses of diorite and other rocks includes alteration of the texture and

[1] 'Manual of Geology,' 2nd ed. p. 93; A. G., *Trans. Geol. Soc. Edin.* ii. p. 301; *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 150; Judd, *Q. J. G. S.* xxx. p. 220; Reyer, *Jahrb. Geol. Reichsanst.* 1879, p. 405, and his 'Beitrag zur Physik der Eruptionen.'

[2] A. G., *Trans. Roy. Soc. Edin.* xxix. p. 476.

even the mineralogical composition of the rocks through which the intrusive material has been erupted. The amount and nature of the change produced vary with the character and bulk of the eruptive mass, as well as with the susceptibility of the surrounding materials to alteration. Diorite, diabase, melaphyre, basalt, felsite, and other eruptive rocks are not infrequently accompanied by considerable metamorphism of the adjacent strata, though the change seldom approaches the intensity of that around large areas of granite. These phenomena are manifested also by intrusive sheets, dykes, veins, and necks. They belong to the series of changes embraced under the head of contact-metamorphism, and are grouped together for description in the next Part (pp. 776-785).

Effects on the Eruptive Mass.—Allusion has been made above to the displacement of rocks by eruptive bosses, as if the original material that filled the present area of these bosses had been blown out, pushed up, or melted down into the advancing column of the igneous magma. If any serious amount of material were incorporated by fusion into an eruptive mass we should expect to be able to detect some change in the chemical composition or crystalline structure of the rock so affected. Reference has already (p. 710) been made to examples of this kind in the case of granites, granophyres, or other acid rocks which have assimilated portions of such a basic rock as gabbro. But though probably on a smaller scale, some comparable change may be expected along the contact of much more basic rocks than granite. There is reason, for instance, to suspect that the thick dolerite sills of Central Scotland, above alluded to, have attacked the strata, particularly the limestones, through which they have risen. The observations and deductions of Dr. Stecher on the variations in the composition of these intrusive sheets (*postea*, p. 775) deserve consideration, for they appear to indicate that considerable petrographical differences may be induced on a basic igneous mass by the incorporation into its substance of portions of the surrounding rocks. A remarkable change is superinduced on basic intrusions when they come in contact with coal or with carbonaceous shales. They become pale in colour and earthy in texture, and assume the aspect of "white trap" (p. 775).

Connection with Volcanic Action.—There can be little doubt that in regard to eruptive masses, particularly of the dioritic, gabbro, and doleritic or basaltic series, though the portions now visible consolidated under a greater or less depth of overlying material, they must in many cases have been directly connected with superficial volcanic action. Some of them may have been underground ramifications of the ascending molten rock, which poured forth at the surface in streams of lava, though these superficial portions have been removed by denudation. Others may mark the position of intruded masses which were arrested in the unsuccessful attempt to open a new volcanic vent. The gabbro and granophyre bosses of the Inner Hebrides were undoubtedly a part of the general Tertiary volcanic phenomena of that region.

Connection with Crystalline Schists.—In some regions masses of diorite, gabbro, diabase, &c., associated with crystalline schists have undergone such a rearrangement of their component minerals as to pass into

amphibolites and hornblende-schists. These changes are well developed in the Saxon Granulitgebirge and in the North of Scotland. They are further referred to at pp. 735, 787; 797, 889, 893, and Figs. 266, 367.

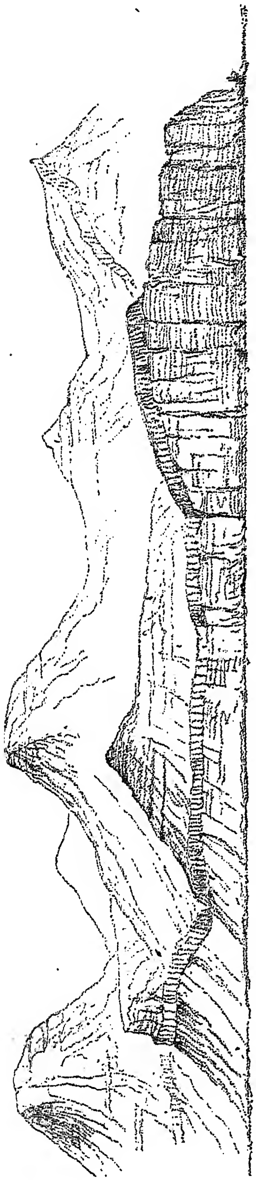

Fig. 301.—Sill intercalated among the Tertiary bedded basalts, Stromö, Faroe Islands.

§ 2. Sills, Intrusive Sheets.

Eruptive masses have been intruded between other rocks, and now appear as more or less regularly defined beds. In many cases, it will be found that these intrusions have taken place between the planes of stratification. The ascending molten matter, after breaking across the rocks, or rather, after ascending through fissures, either previously formed or opened at the time of the outburst, has at last found its path of least resistance to lie along the bedding-planes of the strata. Accordingly it has thrust itself between the beds, raising up the overlying mass, and solidifying as a nearly or exactly parallel cake, sheet, or sill.

It is evident that one of these intercalated sheets must present such points of resemblance to a subaerial stream of lava as to make it occasionally a somewhat difficult matter to determine its true character, more especially when, owing to extensive denudation, or other cause, only a small portion of the rock can now be seen. Intrusive sheets are marked by the following characters, though these must not be supposed to be all present in every case. (1) They do not rigidly conform to the bedding of the rocks among which they are intercalated, but sometimes break across it, and run along on another platform. (2) They catch up and involve portions of the surrounding strata. (3) They sometimes send veins into the rocks above and below them. (4) They are connected with dykes or pipes which, descending through the rocks underneath, have been the channels by which the sills were supplied. (5) They are commonly most close-grained at their upper and under surfaces, and most coarsely crystalline in the central portions. (6) They are rarely cellular or amygdaloidal. (7) The rocks both

above and below them are usually hardened and otherwise more or less altered.[1]

The term "Sill" is derived from the remarkable example in the north of England, which has long been known as the Great Whin Sill.[2] This intrusive sheet is traceable for a distance of 80 miles and has a total area of perhaps not less than 1000 square miles. It varies in thickness from less than 20 to as much as 150 feet, but averages from 80 to 100 feet. It is clearly intrusive, for it breaks across from one platform of strata to another, metamorphosing the rocks with which it is in contact (Fig. 302 and p. 773).

Fig. 302.—Section showing the position of the Great Whin Sill between the Limestone escarpment on the west and the Millstone Grit hills east of Teesdale.
1, Silurian strata ; 2, Carboniferous Limestone series ; 3, the Great Whin Sill, which becomes thinner and rises to a higher stratigraphical position as it goes westward ; 4, Millstone Grit.

Another well-known and (from its association with the Huttonian and Wernerian disputes) classical example of this structure is the mural escarpment called Salisbury Crags at Edinburgh (Fig. 303).[3] This is a sill of crystalline diabase (dolerite), which

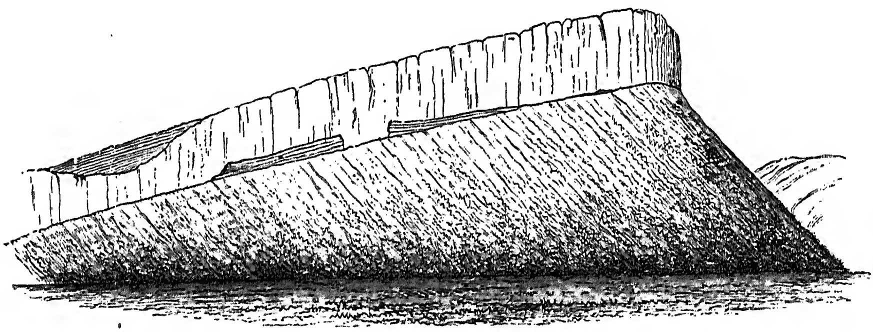

Fig. 303.—Diagrammatic view of Salisbury Crags, Edinburgh—a Sill in Carboniferous sandstones and shales.

can be traced for a distance of 1500 yards, lying among the red and grey sandstones, shales, and impure limestones which lie at the base of the Carboniferous system of Central Scotland. As the general dip of the rocks is north-easterly, the sill forms a lofty cliff facing west and south, from the base of which a long grassy slope of débris stretches

[1] Mr. E. Howe, as above cited (p. 329), has conducted some experiments to illustrate the intrusion of igneous material suggested by the structure of the laccolites of the Black Hills. 21*st Rep. U. S. G. S.* (1901), pp. 163-305.

[2] See Topley and Lebour, *Q. J. G. S.* xxxiii. (1877), p. 406 ; J. J. H. Teall, *op. cit.* 1884 ; Hutchings, *Geol. Mag.* (1898), pp. 69, 123. The word "Sill" was probably applied by the inhabitants to this flat cake of dark stone at the base of the hills, from its fancied resemblance to the sill or threshold of a house.

[3] Another analogous sill which forms the picturesque rock of Stirling Castle has been described by Mr. H. Monckton, *Q. J. G. S.* li. (1895), p. 480.

down to the valley in front. Its thickness at the highest part is about 80 feet, but at a distance of 650 yards to the north this thickness diminishes to less than a half. At first, the diabase might be taken for a conformable sheet, regularly interposed between the sedimentary strata. But an examination of the beds on which it rests shows that it transgressively passes over a succession of platforms, and eventually comes to rest at the east end on strata somewhat lower in geological position than those at the north end. Moreover, another parallel intrusive sheet intercalated in a lower portion of the sand-

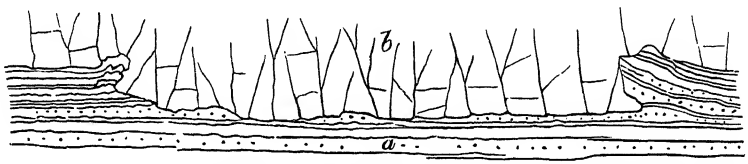

Fig. 304.—Section at base of south front of Salisbury Crags, showing portion of strata cut out by intrusive diabase. *a*, sandstones, shales, &c.; *b*, diabase. Length of section, 22 feet.

stone series gradually approaches the rock of Salisbury Crags. They are both transgressive across the strata, and they appear to unit in a large mass called Samson's Ribs.

On the west front, a large dyke-like mass of the diabase descends vertically through the sandstones, and has been regarded as not improbably a pipe or feeder, up which the molten rock originally rose (Fig. 303). Along the southern face of the escarpment, several instructive exposures show the behaviour of the diabase to the strata through which it has made its way. In Fig. 304, for example, a portion of the underlying

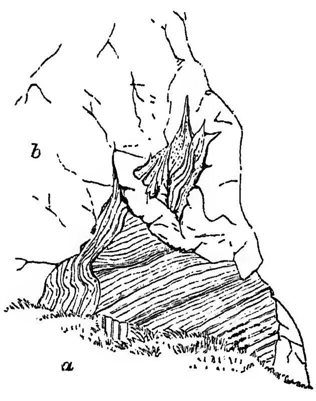

Fig. 305. Fig. 306.

Fig. 305.—Mass of sandstone and shale (*a*) imbedded in the diabase (*b*) of Salisbury Crags, and injected with veins and threads of it.

Fig. 306.—Junction of intrusive diabase with sandstone, Salisbury Crags. Magnified 20 diameters.—The granular portion at the bottom of the drawing is sandstone, a part of which is involved in the diabase that occupies the rest of the slide. The darker portion next the sandstone is a vitreous substance which has been serpentinized. It contains crystals of plagioclase and vapour vesicles drawn out in the direction of flow. Above the darker part the glassy condition rapidly passes into ordinary but minutely crystalline diabase. The rock has been considerably altered, calcite occupying many of the vesicles and fissures.

strata having been carried away, the diabase has wedged itself below one of the remaining broken ends. Again, veins and threads of the eruptive rock have been injected into fragments of the strata caught up in its mass (Fig. 305). The strata in

contact with the diabase have been much hardened, the shales being converted into a kind of porcellanite, and the sandstones into quartzite.[1] The diabase in the centre of the bed is a coarse-grained rock, in which the component minerals can readily be detected with a lens, or even with the unassisted eye. But as it approaches the sedimentary beds, above and below, it becomes finely crystalline. I have had sections cut for the microscope, showing the actual junction of the two rocks (Fig. 306). In these it is interesting to observe that the diabase, for about the eighth of an inch inwards from its edge, consists mainly of an altered glass in which lie well-formed crystals of triclinic felspar and numerous opaque tufted microlites (probably augite and iron ores). An inch back from the edge, the glass and the microlites have alike disappeared, and the rock is merely a crystalline diabase, though finer in grain than in the central portions of the bed. Numerous steam- or gas-vesicles occur in the vitreous part, some of them empty, but mostly filled with calcite or a brown ferruginous earth. There can be little doubt that the vitreous structure of this marginal film was originally that of the whole rock. The thinness of the glassy crust is in harmony with all that is known as to the feeble thermal conductivity of lava. When the rock was intruded, it was no doubt a molten glass containing much absorbed vapour, the escape of which at its high temperature was probably the main agent in indurating the adjacent strata. This greater closeness of texture at the contact, due to rapid solidification against a cold surface, forms one of the distinguishing marks of an intrusive as contrasted with a contemporaneous sheet (p. 753). Microscopic examination of these marginal parts in many of the intrusive sheets of Central Scotland, shows that even where no distinct glass remains, the rock is crowded with black opaque microlites arranged in a delicate geometric network. Back from the surface of contact, the microlites disappear, and the magnetite or titaniferous iron assumes its ordinary crystalline and often indeterminate or imperfect contours.

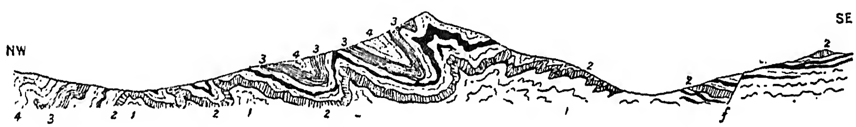

Fig. 307.—Section across Schiehallion, Perthshire, Scotland.
1, Mica-schists; 2, Limestone bands; 3, Graphitic schists; 4, Quartz-schists; *f*, Fault.
The thick black lines mark intercalated epidiorite sills.

In regions of crystalline schists, sills sometimes play a conspicuous part. Thus, in the Scottish Highlands, sheets of intrusive material injected among the original sediments have been plicated and metamorphosed together with these strata, and now appear as epidiorite and amphibolite-schist (Figs. 307 and 370). They occur on various horizons, and break across into higher or lower parts of the series.

Another lithological characteristic of the intrusive, as compared with the interstratified sheets, is the considerable variety of composition and structure which may be detected in different portions of the same mass. A rock which at one place gives under the microscope a crystalline-granular texture, with the mineral elements of diabase, will at a short distance show a coarsely crystalline texture with abundant orthoclase and free quartz—minerals which do not belong to normal diabase—or may be traversed by veins of fine-grained siliceous material. These

[1] Mr. Sorby has observed in specimens from this locality sliced by him for microscopic examination that the fluid cavities in the quartz-grains have been emptied. *Q. J. G. S.* xxxvi., Address, p. 82. But see Dr. Stecher's papers quoted p. 775. He describes the contact phenomena of the Carboniferous sills in the basin of the Forth.

differences, like those above referred to as noticeable among amorphous bosses, seem to point to successive stages in the consolidation of a molten magma, of which the more basic constituents separated first. But sometimes they suggest that great intrusive sheets have here and there involved and melted down portions of rocks, and have thus acquired locally an abnormal composition.[1]

Mr. G. K. Gilbert has described, under the name of "Laccolite," a variety of the sill-structure, which he observed originally in the Henry Mountains, Southern Utah, and which has since been recognised in many other districts. Large bosses of igneous material have risen from beneath, but instead of finding their way to the surface, have spread out laterally and pushed up the overlying strata into a dome-shaped elevation (Fig. 308). Here and there, smaller sheets proceeding from the main masses have been forced between the beds, or veins have been injected into fissures, and the overlying and contiguous strata have been considerably metamorphosed.[2] Subsequent denudation may expose a laccolite as a boss (p. 723).

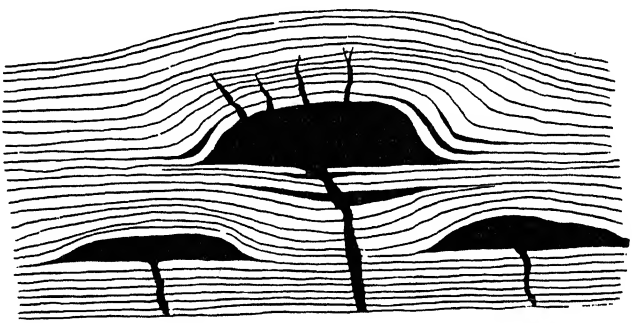

Fig. 308.—Ideal section of three "Laccolites," after Gilbert.

Effects on Contiguous Rocks.—Admirable examples of the alteration produced by eruptive masses are not uncommonly presented at the contact of intrusive sheets with the surrounding rocks. Induration, decoloration, fusion, the production of a prismatic structure, conversion of coal into anthracite, of limestone into marble, and other alterations, may be observed. The nature of these changes is described at p. 766 *et seq.*

Connection with Volcanic Action.—Many volcanic rocks occur in the form of sills, as quartz-porphyry, rhyolite, orthophyre, trachyte, diorite, melaphyre, diabase, dolerite, basalt, serpentine and others. The remarks above made regarding the connection of intrusive bosses with

[1] A. G., *Trans. Roy. Soc. Edin.* xxix. p. 492. Clough, *Geol. Mag.* 1880, p. 433. See also J. J. H. Teall, *Q. J. G. S.* xl. p. 247; xlviii. p. 104, and Stecher's papers already cited.

[2] 'Geology of the Henry Mountains,' U.S. Geog. and Geol. Survey, Washington, 1877; *Journ. Geol.* iv. p. 816; Whitman Cross, 14*th Ann. Rep. U.S. Geol. Surv.* 1892-93. A similar structure was figured and described by C. Maclaren, 'Geol. of Fife and Lothians,' 1839, pp. 100, 101. The gabbros of Skye have been injected in this way into the sheets of the great basalt-plateau. A. G., *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 122. See also J. D. Dana, *Amer. Journ. Sci.* xliii. (1891), p. 79.

volcanic action may be repeated with even greater definiteness here. Intrusive sheets abound in old volcanic districts, intimately associated with dykes and surface-outflows, thus bringing before our eyes traces of the underground mechanism of volcanoes. They frequently occur among the rocks that lie beneath a mass of ejected lavas and tuffs, or traverse the lower, sometimes even the upper parts of the volcanic mass. In some cases, therefore, they may mark later stages of eruption when the orifices of discharge had become choked up and the subterranean energy only sufficed to inject the magma between the bedding of the rocks below ground but not to impel it to the surface, while in other instances they may belong to the time before the magma had been able to effect an egress to the surface, and when it was consequently forced between the strata at some depth below. It is observable that later intruded masses are often more acid than the lavas previously erupted.[1]

Among the Palæozoic and Tertiary volcanic regions of Britain numerous illustrations of associated sills are to be found. Some of the most striking are those that emerge from beneath the great erupted masses of Arenig and Bala age in North Wales. Admirable examples occur among the Carboniferous volcanic rocks of the basin of the Forth.[2] The Tertiary sills injected among Carboniferous and Cretaceous rocks of Antrim and the Jurassic rocks of the Inner Hebrides are likewise conspicuous for size and abundance.[3] The extent to which lava may be injected in thin layers between the planes of the strata is strikingly displayed near the base of the great basalt plateau of Skye. In

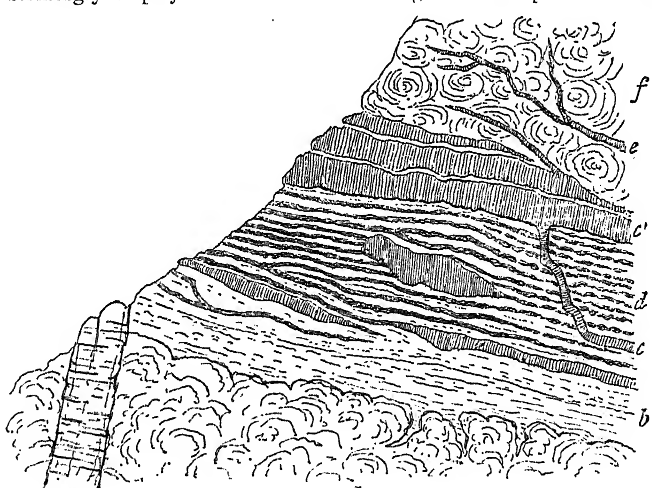

Fig. 309.—Thin Intrusive Sheets and Veins injected into carbonaceous shales lying between lavas, south of Portree, Skye.

Fig. 309, for example, a section is represented of a band of carbonaceous shale, eight or nine feet thick, intercalated between a slaggy vesicular dolerite (*a*) and a finely vesicular

[1] A. G., *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 143. *Q. J. G. S.* xlviii. (1892), Address, p. 177. 'Ancient Volcanoes of Great Britain,' ii. p. 477.

[2] *Trans. Roy. Soc. Edin.* xxix. p. 474.

[3] *Op. cit.* xxxv. (1888), p. 111. 'Ancient Volcanoes of Great Britain,' chaps. xlii. xliv. and xlviii.

basalt (*f*). In the portion of this band marked *d*, two or three feet in thickness, more than a dozen thin sills of basalt have been thrust between the strata of shale. Some of these have broken up into detached nodule-like portions, so as to resemble true sedimentary concretions. The thicker sheets (*c′*) are here and there connected with veins (*c*), which cross the thinner sills or (*e*) traverse the overlying basalt (*f*). Probably the latest rock of the group is the dyke (*g*). Such a section brings vividly before the mind the energy and persistence with which molten material has been injected along those platforms whereon, as in this shale band, it could most easily force its way.[1]

§ 3. Veins and Dykes.

The term "vein" is rather vaguely employed by geologists. It is used as the designation of any mass of mineral matter which has solidified between the separated walls of a fissure. When this mineral matter has

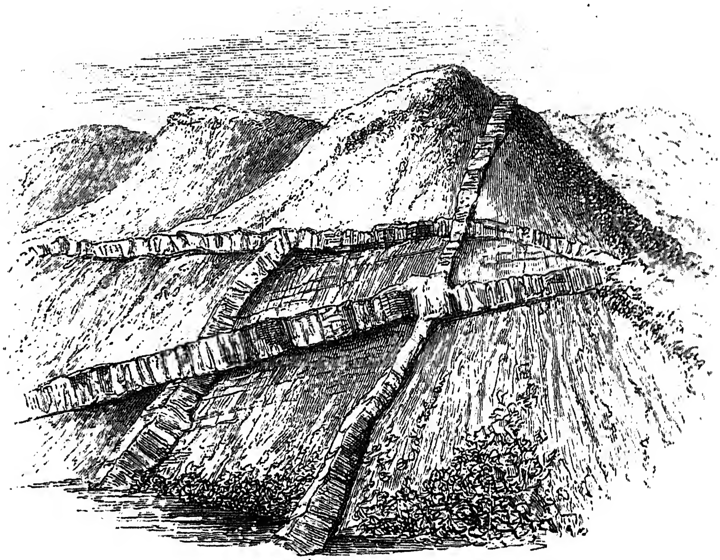

Fig. 310.—Intrusive Veins and Dykes of Andesite in Tuff of a Volcanic "Neck," Renfrewshire.

been deposited from aqueous solution or from sublimation, it forms what is known as a *mineral-vein* (p. 812). When it has been injected in a molten or pasty state into some other rock, it is an *eruptive vein*, or, if in a vertical wall-like mass, a *dyke*. When it forms part of the igneous rock in which it occurs, but belongs to a later period of consolidation than the portion into which it has been injected, it has been called a *contemporaneous vein.* When it has crystallized or segregated out of the component materials of some still unconsolidated, colloid, or pasty rock, it is called a *segregation vein.*

Eruptive or Intrusive Veins and Dykes are portions of once-melted, or at least pasty matter, which have been injected into rents of previously solidified rocks. When traceable sufficiently far, they may be seen to

[1] 'Ancient Volcanoes of Great Britain,' ii. p. 311.

swell out and merge into their parent mass, while in the opposite direction they may become attenuated into mere threads. Sometimes they run for many yards or miles in tolerably straight lines. When this takes place along vertical or highly-inclined stratification, they look like interstratified beds, though really intrusive. They may frequently be found to break across the bedding in a very irregular manner.

No rock exhibits more instructively than granite the numerous varieties of form assumed by Veins.[1] Three distinct kinds of granite veins may be observed. 1st, Protrusions of the ordinary granite extending from the main masses into the surrounding rocks and demonstrating the intrusive character of the granite (Figs. 311, 312). These varying in breadth from several feet or many yards down to fine filaments or threads, are often remarkably abundant and markedly irregular in the manner in which they branch and intersect. Where they are several yards broad their texture, at least in the central parts, may not sensibly differ from that of the main granite mass, though it is apt to become finer especially as the veins diminish in breadth. It has been already pointed out that round some bosses of granite the adjacent rocks are injected or impregnated

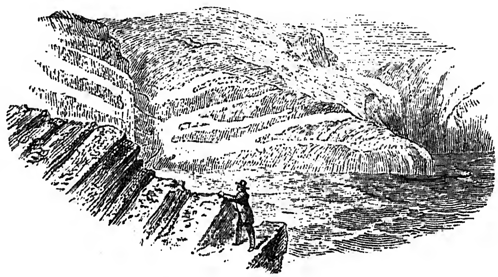

Fig. 311.—Granite Veins.

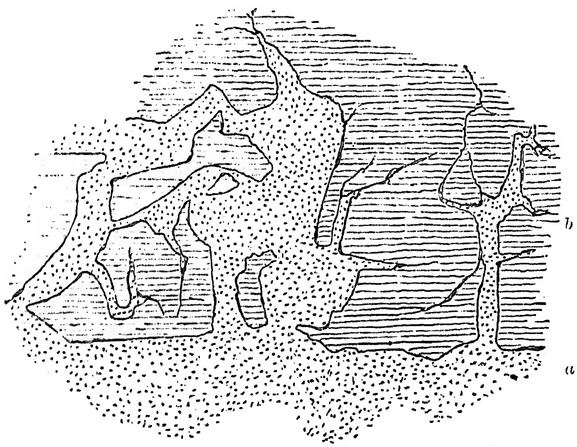

Fig. 312.—Section of granite (*a*), sending a network of veins into slate (*b*); Cornwall (*B.*).

with abundant minute threads or veins of granite-substance, like layers or leaves parallel with the stratification or foliation, and that the absence of "chilled" edges may be due to the high temperature of the rocks into which the granite was injected (p. 728).

In the Tertiary volcanic districts of the west of Scotland large bodies of granite and granophyre have been intruded into other volcanic rocks. Not only has the acid

[1] Credner, *Z. D. G. G.* (1875), p. 104; (1882), p. 500. E. Kalkowsky, *op. cit.* (1881) p. 690.

material filled up broad fissures, so as to form conspicuous dykes, but it has been injected into a network of minute cracks, as if the invaded rock had been shattered by energetic explosions before the entry of the granitic magma (Fig. 313).[1]

Besides a usual greater closeness of texture than that of their parent mass, intrusive veins sometimes present considerable differences in mineralogical composition. The mica, for example, may be reduced to exceedingly minute and not very abundant flakes, and may almost disappear. The quartz also occasionally assumes a subordinate place, and the rock of the veins passes into one of the varieties of felsite, quartz-porphyry, elvanite, aplite or eurite.[2]

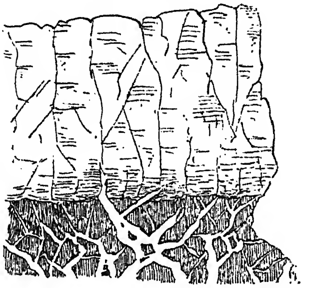

Fig. 313.—Section of two sheets of gabbro, the lower of which has been penetrated from below by a multitude of irregular veins of granophyre, St. Kilda.

It is in the metamorphosed belt encircling an intrusive boss of granite, that eruptive veins are typically developed and most readily studied. In Cornwall, for example, the slates around the granite bosses are abundantly traversed by veins or dykes of granite and of quartz-porphyry (*elvans*), which are most numerous near the granite (Fig. 314). They vary in width from a few inches or feet to 50 fathoms, their central portions being commonly more coarsely crystalline than the sides. They frequently

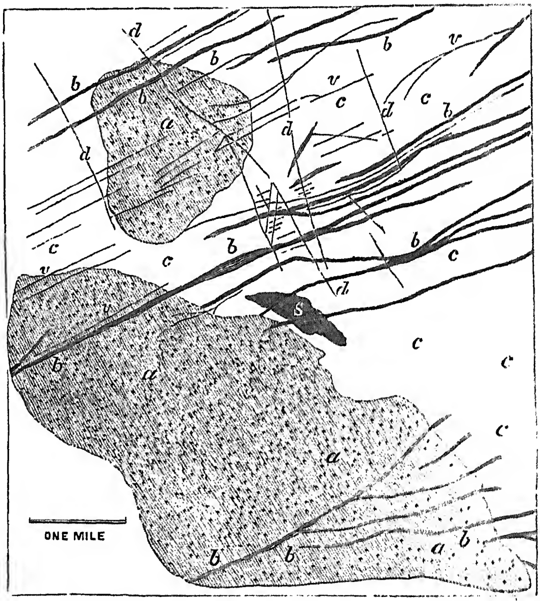

Fig. 314.—Map of part of the Mining District of Gwennap, Cornwall (*B.*).
a a, Granite; *c c*, Schistose rocks; *b b*, Elvan dykes; *s*, "Greenstone"; *v v*, *d d*, two intersecting series of mineral-veins.

enclose angular fragments of slate (p. 724). In the great granite region of Leinster

[1] 'Ancient Volcanoes of Great Britain,' ii. p. 413.

[2] See a reference to the Bodegang, *ante*, p. 208; also Hawes, *Amer. Journ. Sci.* xxi. (1881), p. 244.

Jukes traced some of the elvans for several miles running in parallel bands, each only a few feet thick, with intervals of 200 to 300 yards between them. Around some of the granite bosses of the south of Scotland similar veins of felsite and porphyry abound. The granite of the Wahsatch Mountains in Utah, which rises through the Upper Carboniferous limestones, converting them into white marble, sends out veins of granite-porphyry and other crystalline compounds. In short, all over the world it is common for eruptive bosses of this rock to have a fringe of intrusive veins (*Apophyses*).

2. Veins which cut through the granite itself, though they must be regarded as later than the rock which they actually traverse, may yet represent lower, still liquid portions of the granitic magma which have been forced by earth-movements into rents in the partially or wholly solidified granite. They are generally finer in grain than the granite around them, and differ more or less from it also in composition, especially in their greater acidity (Fig. 315).

3. Pegmatites or pegmatitic veins (Fig. 315) are distinguished by the manner in which their component minerals, notably the quartz and felspar, are intergrown (see pp. 128, 206). Much discussion has arisen as to the origin of such veins. They evidently cut the ordinary granite and in so far may be regarded as intrusive veins. But they could not have been injected in their present crystalline condition. Their material may have been squeezed up from some lower, still liquid part of the granitic magma, but their remarkable crystalline structure must have been afterwards superinduced by some process of segregation or rearrangement and crystallization of their materials.[1]

Many other eruptive rocks (diorite, diabase, melaphyre, basalt, &c.) present admirable examples of intrusive (even pegmatitic) veins. These are generally distinguished from those of granite by the much feebler metamorphism with which they are attended.

The "Contemporaneous Veins" of older writers included those veins in crystalline rocks which though differing sufficiently from the surrounding material to be easily distinguished, resembled it so closely as to indicate that they were probably a part of it. The veins above described under No. 2 are examples. But they are not confined to granite, since they may not infrequently be observed in sheets of gabbro, diorite, dolerite, diabase, and other eruptive rocks (Fig. 316). They are more particularly to be seen in sills and bosses. They run as straight, curved, or branching ribands, usually not exceeding a foot in thickness. They are finer in texture than the rock which they traverse. Close examination of them shows that, instead of being sharply defined by a definite junction line with the enclosing rock, they are welded into that rock in such a way that they cannot easily be broken along the plane of union. This welding is found to be due to the mutual protrusion of the component crystals of the vein and of the surrounding rock—a structure sometimes admirably revealed under the microscope. Veins of this kind evidently point to some process whereby, into rents formed in the deeply buried and at least partially consolidated or possibly pasty or jelly-like mass, there was an injection of similar material from some still unsolidified part of the mass, with a transfusion or exosmosis of some of the crystallizing minerals along the mutual boundaries. Such veins are to be distinguished from the true "Segregation-veins," which are irregular bands,

[1] The student will find a historical summary of opinion as to the origin of pegmatite veins in Professor Brögger's great work on the minerals of the syenite-pegmatite veins of Southern Norway, Part i. p. 215 *et seq.* He distinguishes four successive phases in the development of these veins, pp. 148-181.

usually of more coarsely crystalline material, not infrequently to be seen in intrusive sheets, wherein the constituent minerals have crystallized out in a much more conspicuous form than in the main mass of the surrounding rock along certain lines or around particular centres. These are probably due to some kind of segregation from the surrounding mass, though the conditions under which it took place have not yet been satisfactorily explained.[1] Segregation-veins occur among the crys-

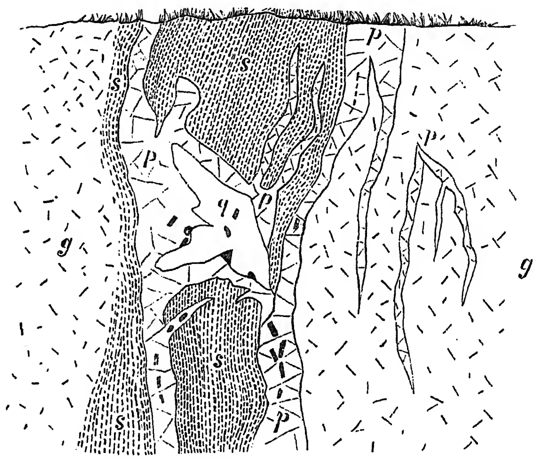

Fig. 315.—Pegmatite Vein associated with foliated granite. Rubislaw Quarry, Aberdeen. *g g*, Ordinary granite of the mass; *p p*, coarse pegmatite veins; *s s*, foliated granite passing insensibly into *g*; *q*, mass of quartz. The black patches in *p* and *q* are nests of schorl.

talline schists and even in sedimentary rocks which have been crushed and metamorphosed, as in the Torridon arkose of Loch Carron (Fig. 268).

Along the margin of segregation-veins in granite a foliated structure of the rock may be occasionally observed, as in some of the large granite quarries near Aberdeen (Fig. 315). Coarse pegmatite veins abounding

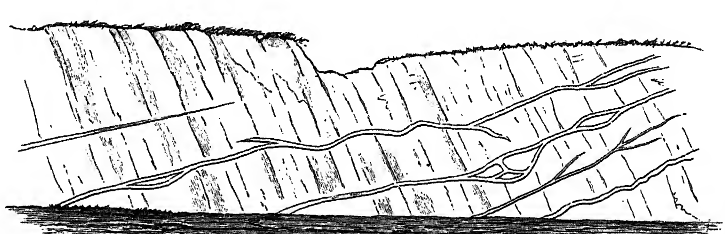

Fig. 316.—"Contemporaneous Veins" in diabase.

in large plates of muscovite, black tourmaline, and quartz, with occasional crystals of beryl and other minerals, merge into the surrounding granite, which for a few inches along the contact has a foliated structure precisely

[1] For some illustrations see *Trans. Roy. Soc. Edin.* xxxv. (1888), pp. 113, 115, 118, 131.

resembling that of a fine gneiss. This foliation may indicate motion of the granite mass along a line of fissure, while the rock itself or the material forced up into the fissure was still capable of molecular re-arrangement.

Dykes are veins of eruptive rock, filling vertical or highly-inclined fissures, and are so named on account of their resemblance to walls (*Scotice*, dykes).[1] Their sides are often as parallel and perpendicular as those of built walls, the resemblance to human workmanship being heightened by the numerous joints which, intersecting each other along the face of a dyke, remind us of well-fitted masonry. Where the surrounding rock has decayed, the dykes may be seen projecting above ground

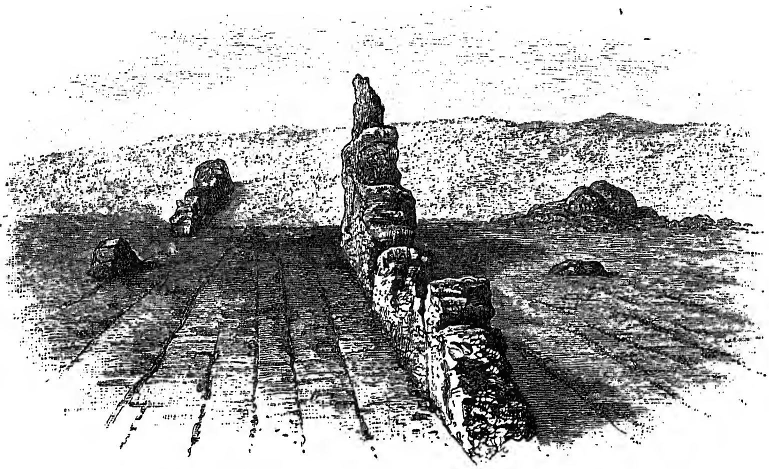

Fig. 317.—Dykes in volcanic tuff of a "neck"; shore, Elie, Fife.

exactly like walls (Fig. 317); indeed, in many parts of the west of Scotland they are made use of for enclosures. The material of the dykes has in other cases decayed, and deep ditch-like hollows are left to mark their sites. The coast-lines of many of the Inner Hebrides and of the Clyde Islands furnish numerous admirable examples of both kinds of scenery. Dykes are characteristically displayed round volcanic centres.

The term dyke may be applied to some of the wall-like intrusions of quartz-porphyry, elvanite, and even of granite, but it is more typically illustrated among the basic and intermediate igneous rocks such as basalt, diabase, andesite, diorite, &c., while occasionally dykes may be observed

[1] On the Mechanism of Dykes see Mallet, *Q. J. G. S.* xxxii. (1876), p. 472. The structure of dykes is fully discussed in 'Ancient Volcanoes of Great Britain,' particularly in reference to those of Tertiary time. For an account of another dyke region see J. F. Kemp and V. F. Masters on those of Lake Champlain, *Bull. U. S. G. S.* No. 107 (1893); the dykes of the Christiania district are described in Brögger's work on the Syenitpegmatitgänge, already cited.

of even tuff and volcanic agglomerate.[1] Veins have been injected into irregular branching cracks; dykes have been formed by the welling upwards of liquid or plastic rock in vertical or steeply inclined fissures, though obviously there is no essential difference between the two forms of structure. Sometimes the line of escape has been along a fault. In Scotland, however, which may be regarded as a typical region for this kind of geological structure, the vast majority of dykes rise along joints or fissures which have no throw, and are therefore not faults. On the contrary, the dykes may be traced undeflected across some of the largest faults in the midland counties.

Dykes differ from veins in the greater parallelism of their sides, their verticality, and their greater regularity of breadth and persistence of direction. They sometimes occur as mere plates of rock not more than an inch or two in thickness, at other times they attain a breadth of twelve fathoms or more. The smaller or thinner dykes can seldom be traced more than a few yards; but the larger examples may be followed sometimes for many miles.

Thus, in the south and west of Scotland, a remarkable series of basalt and andesite dykes can be traced across all the geological formations of that region, including the older Tertiary basalt-plateaux. They run parallel to each other in a general north-west and south-east direction for distances of twenty and thirty miles, increasing in numbers towards the north-west, and they have been assigned to the great volcanic activity of Tertiary time. A dyke of the same series crosses the north of England, from near the coast of Yorkshire for about 100 miles inland. A complex system of massive pre-Cambrian dykes traverses the Archæan gneiss of N.W. Scotland.

Though the wall-like form is predominant among dykes, it may readily pass into vein-like ramifications and intrusive sheets (Figs. 303, 309, 310). The molten material took the channels that happened to be most available. If the fissure bent off at an angle from its previous trend, or if another adjacent fissure happened to be more convenient, the eruptive rock might change its course. Again, while the ascending lava, under the hydrostatic pressure of the mass below, rose in one main fissure, portions of it might find their way into neighbouring parallel rents, and enclose wall-like portions of rock within the dyke, as in Fig. 318, where the total breadth of the main dyke, including the sandstone between the two arms, is about thirty feet, the sandstone being gently inclined, and the portions enclosed between the arms of the dyke having been greatly indurated.

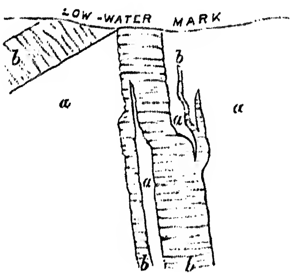

Fig. 318.—Plan of dykes (*b b*) cutting sandstone (*a a*); shore, Gourock, Renfrewshire.

It must be kept in mind, however, that irregular expansions and contractions of dykes may sometimes be caused by subsequent movements of the terrestrial crust. The dykes, for instance, may be plicated together

[1] The occurrence of "sandstone dykes" has already been noticed, *ante*, p. 665.

with the rocks among which they have been intruded, and the folds may afterwards be pressed in such a way as to give rise to alternate or irregularly distributed enlargements and constrictions, or a similar effect may be produced by shearing or by faulting.[1] Mr. Clough has found that in a great system of dykes traversing the crystalline schists of Argyllshire frequent attenuations of the dykes are produced by faults.

In internal structure, considerable differences may be detected among dykes. The rock may appear (*a*) with no definite structure of any kind beyond irregular jointing; (*b*) columnar, the prisms striking off at right angles from the walls, and either going completely across from side to side, or leaving a central non-columnar part in which they branch and lose themselves; when the side of a dyke having this structure is laid bare, it presents a network of polygonal joints formed by the ends of the prisms which, if the dyke is vertical, lie of course in a horizontal position, whence they depart in proportion as the dyke is inclined: occasionally the prisms are as well-formed as in any columnar bed of basalt; (*c*) jointed parallel with the walls, the joints being sometimes so close as to cause the rock to appear as if it consisted of a series of vertical plates or strata: this platy character is due doubtless to contraction in cooling between parallel walls, and when it occurs in basalt-dykes is best developed near the margins; (*d*) vesicular or amygdaloidal, lines of minute vesicles having been formed parallel with the walls, and attaining their greatest number and size along the centre of the dyke (Fig. 319).

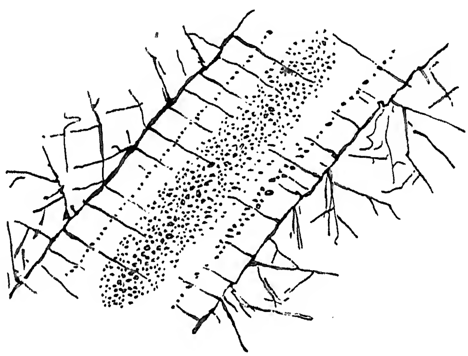

Fig. 319.—Arrangement of bands of amygdales in a dyke, Strathmore, Skye.

As a rule, the outer parts of a dyke of crystalline rock, like the upper and under surfaces of an intrusive sheet, are finer grained than the centre, sometimes, where the chilling of the molten rock has been rapid, passing into a veneer of glass. Basalt veins have not infrequently such an external vitreous coating (tachylyte, hyalomelan, &c.) It occasionally happens also that the central portions of a basalt or andesite dyke are glassy, of which structure several cases have been observed in Scotland; perhaps in these instances the dyke has opened along its centre, and a fresh uprise of more glassy material has risen in the fissure.[2]

In some broad dykes there has been room for a certain amount of differentiation during the cooling of the mass. Professor A. C. Lawson has described some examples from the Rainy Lake region of Canada,

[1] Compare the structure illustrated by Fig. 346. See also Harker, *Geol. Mag.* 1889, p. 69, and the account of the pre-Cambrian rocks in Book VI. Part I.

[2] See *Proc. Roy. Phys. Soc. Edin.* v. (1880), p. 241.

which show a considerably greater percentage of silica in the centre than at the sides. In one case, while the margin had the characters of an andesite with 47·8 per cent of silica, it shaded off inwards into an ophitic diabase, and then into a uralitic quartz-gabbro, in which the proportion of silica was found to be 57·5 per cent.[1]

Multiple and Compound Dykes.[2]—Numerous examples have been observed where a dyke has been formed by more than one intrusion of molten material. The original fissure, after having been filled with the intrusive material, has again been rent open and has once more been occupied by a similar injection. This re-opening of a fissure has sometimes occurred repeatedly. A remarkable instance may be seen on the island of Seil, Argyllshire, where no fewer than ten distinct intrusions can be counted between the walls of a single fissure (Fig. 320). Some

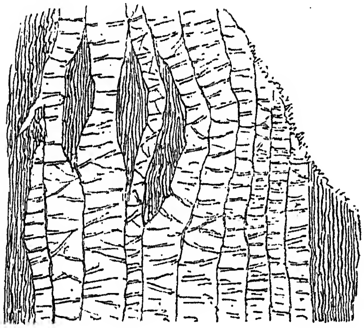

Fig. 320.—Multiple dolerite-dyke traversing and enclosing black slate, Seil Island, Argyllshire.

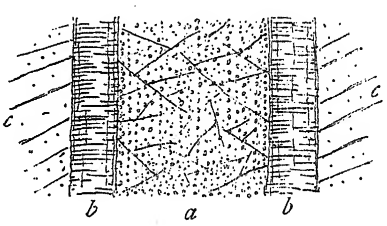

Fig. 321.—Compound dyke, Market Stand, Broadford, Skye.
a, strongly spherulitic Granophyre ; *b b*, Basalt dykes ; *c c*, Torridon Sandstone.

of these separate bands of similar material are distinguished from each other by a narrow selvage of black glass, which is occasionally two inches broad but dies away into a mere film, while one of them displays cavities 3 or 4 inches in diameter, lined with pea-like spherules of glass.[3]

In some cases the subsequent infilling has been supplied by a totally different material from that of the first. Hence arise Compound or Composite dykes (Fig. 321).[4] The earliest injection may have consisted

[1] *Amer. Geol.* vii. (1891), p. 153 ; *Proc. Canad. Inst.* 1887, p. 173 ; *Ann. Rep. Geol. Surv. Canada*, 1887-88, Part F. More usually the vitreous part is more siliceous than the rest of a basic rock (*ante*, p. 236).

[2] 'Ancient Volcanoes of Great Britain,' ii. p. 159.

[3] Summary of Progress of Geological Survey for 1898, p. 155. An excellent example of a multiple dyke is described by Professor A. C. Lawson from the north-east of Lake Superior, where in a breadth of 14 feet no fewer than twenty-eight separate bands of diabase from one to 6½ inches broad traverse a mass of granite. *Amer. Geol.* xiii. (1894), p. 293.

[4] Professor Judd has described the remarkable examples first brought to notice by Jameson in the island of Arran. *Q. J. G. S.* xlix. (1893), p. 536.

of andesite, basalt, or some other dark rock, rich in ferro-magnesian constituents, while the later may be a pale acid rock, such as granophyre or granite. Although the later intrusion may traverse the earlier igneous mass in any irregular manner, it has been observed among the Inner Hebrides, where dykes of this type are by no means rare, that the basic and acid constituents are usually ranged as parallel bands, an acid one in the centre, with a more basic band on either side. The evidence where obtainable shows that the acid part of these dykes is latest, and that it has not split a basic dyke up the middle but has forced its way between the two portions of a double dyke, sometimes invading a multiple dyke, cutting a portion of it obliquely, and even dissolving a portion of the basic walls between which it ascended.[1]

Intersecting Dykes.—In volcanic districts it has frequently happened that new fissures have been opened across already existing dykes, and that they have been filled by the uprise of fresh lava in them. Hence some dykes are found to be intersected by others. While the mere fact of this intersection may be taken to show a succession of injections of molten material, it is not always easy to determine which is the older of two dykes. As a general rule, however, the presence of the fine-grained margin or "chilled edge" may be relied on as a test of relative age. The dyke which carries its "chilled edge" across another dyke must be the later of the two; or when this criterion fails, it may be possible to determine that the "chilled edge" of one of the dykes is truncated by the other, and consequently marks the older intrusion. In some regions extraordinary complications have arisen where the ground has been repeatedly fissured, and where successive injections of lava have been made into the rents. In Fig. 322, for example, at least five dykes intersect each other. Three of these have the prevalent north-westerly trend. They are cut by one which runs a little north of east, and this is in turn traversed by one that trends in a north and south direction.[2]

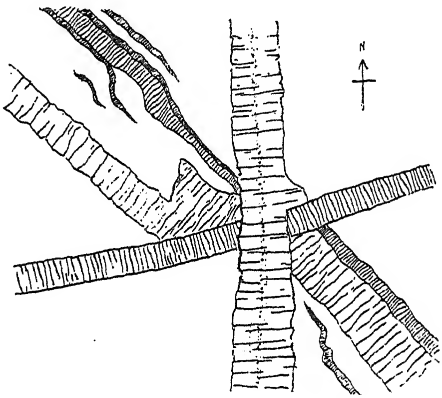

Fig. 322.—Ground plan of intersecting dykes in Lias limestone, shore, east of Broadford, Skye.

Effects on Contiguous Rocks.—These are similar to the changes produced by intrusive sheets and other eruptive masses. Induration is the most frequent kind of alteration. Remarkable examples have been observed where limestones in contact with dykes have had a saccharoid crystallization of the calcite superinduced upon them, and where even

[1] 'Ancient Volcanoes of Great Britain' ii. p. 161.

[2] *Op. cit.* ii. p. 159.

new crystalline silicates have been developed. This subject is more particularly discussed at p. 766, under the head of Contact-metamorphism.

§ 4. Necks.

Under this term are included the filled-up pipes or funnels of former volcanic vents. Every series of volcanic sheets poured out at the surface must have been connected either with fissures, or with orifices drilled through the terrestrial crust. On the cessation of the eruptions, these

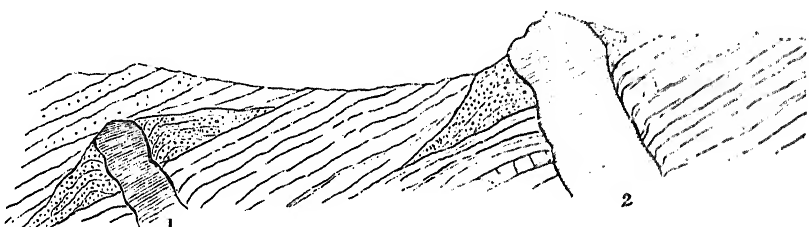

Fig. 323.—Diagram-section to show the structure of old volcanic vents, and how they may be concealed and exposed

1, Tuff cone with basalt plug still buried under sedimentary accumulations; 2, Tuff cone and basalt plug partially exposed by denudation.

orifices have remained filled with lava or with fragmentary matter. But unless subsequent denudation has removed the overlying cone, a vent lies buried under the materials which came out of it. So extensive, however, has been the waste of the surface in many old volcanic regions that the vents have been laid bare. In Fig. 323 two volcanic funnels are represented, one of them still buried under overlying formations, the other

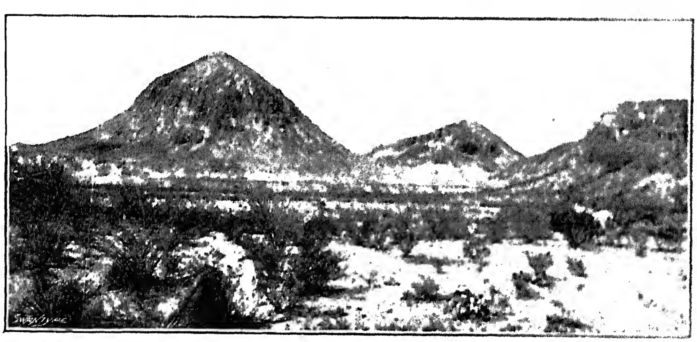

Fig. 324.—Volcanic Necks, Texas. Photograph by Mr. R. T. Hill, U.S. Geol. Survey.

partially exposed by denudation. The study of volcanic Necks brings before us some of the more deep-seated phenomena of volcanic action, that cannot usually be seen at a modern volcano.

A Neck is circular or elliptical in ground-plan, but occasionally more irregular and branching, and may vary in diameter from a few yards

(Fig. 325) up to two miles, or even more. It descends into the earth perpendicularly to the stratification of the formation with which it is chronologically connected. Should rocks originally horizontal be subsequently tilted, a neck associated with them might be thrown more or less out of the vertical (Fig. 323).' As a rule, however, the

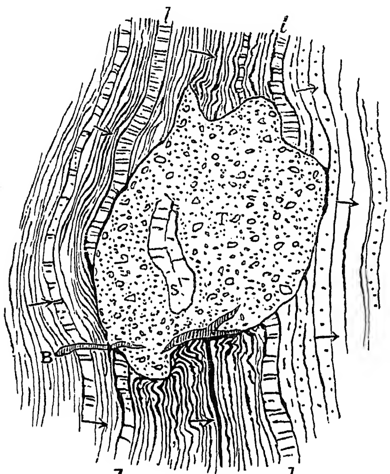

Fig. 325.—Plan of Neck, probably of Permian age, shore, near St. Monan's, Fife.

l l, beds of limestone; *c*, thin coal-seam; B, basalt veins; S, large bed or block of sandstone. The Neck, T, measures about 60 by 37 yards. The arrows mark the dip of the strata.

vertical descent of necks into the earth's crust appears to have been comparatively little interfered with. In external form, necks commonly rise as cones or dome-shaped hills (Figs. 324, 326, 328, 329). This contour, however, is not that of the original volcanoes, but is due to denudation. Occasionally the rocks of a neck have been so worn away that a great hollow, suggestive of the original crater, occupies their site. (Fintry Hills, Stirlingshire.)[1]

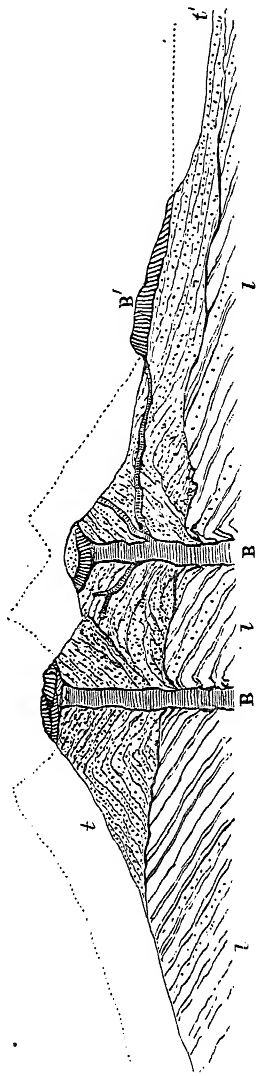

Fig. 326.—Section of the volcanic neck of Largo Law, Fife.

l l, Lower Carboniferous strata; *t*, tuff of cones; *t'*, tuff of area around the cones; B B, basalt filling central pipes of the vents and lateral veins; B', basalt, which may have flowed out at the surface. The dotted lines are suggestive of the original outline of the hill.

[1] For some striking views of denuded volcanic necks see Captain Dutton's Report on Mount Taylor and the Zuñi Plateau, *6th Ann. Rep. U.S. Geol. Survey*, 1884-85. Compare also *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 100; and Geological Survey Memoir on East Fife, 1902. Examples of necks with connected lavas and tuffs are shown in Figs. 328 and 389.

It might be supposed that necks should always rise on lines of fissure. But in Central Scotland, where they abound in rocks of Carboniferous age, it is quite exceptional to find one placed on a fault. And they seem to be often, if not generally, independent of the structure of the visible part of the crust through which they rise (*ante*, p. 279).

The materials filling up ancient volcanic orifices may be (*a*) some form of lava, as rhyolite, granophyre, andesite, gabbro, diabase, or basalt; or (*b*) the fragmentary materials which fell back into the throat of the volcano and finally solidified there. In many instances, both kinds of rock occur in the same neck, the main mass consisting of agglomerate or tuff with a central pipe or numerous veins of lava. Among the Palaeozoic volcanic districts of Britain, necks are not infrequently filled with some acid rock, such as a dacite, orthophyre or "felsite," even where the surrounding lavas may be basic. The great vent of the Braid Hills near Edinburgh, belonging to the time of the Lower Old Red Sandstone, is filled with rhyolitic tuff containing 70 per cent of silica, while the lavas which flowed from it are andesites and diabases with not more than 50 per cent of this acid.

In some necks composed of eruptive rock, the material appears arranged in successive spherical shells, which may be supposed to be due to the protrusion of successive portions of the pasty or viscous mass one within the other, the outer layers thinning away over the crown of the dome as they were attenuated by the ascent of fresh material from below.[1] Or we may suppose that the top of the plug sometimes solidified, and that subsequent emissions of lava rose through rents in the crust, and flowed down the outside of the vent.

The fragmentary materials in necks consist mainly of different lava-form rocks imbedded in a gravelly *peperino*-like matrix of more finely comminuted débris of the same rocks; but they also contain, sometimes in abundance, fragments of the strata through which the necks have been drilled. When occasionally, as in some of the Maare of the Eifel, these non-volcanic fragments constitute most of the débris (p. 326), we may infer that after the first gaseous explosions, the activity of the vent ceased, without the rise of the lava-column or its ejection in dust and fragments to the surface. So unchanged are many of the pieces of sandstone, shale, limestone, or other stratified rock in the necks, that they have evidently never been exposed to any high temperature. In some cases, however, considerable alteration is displayed. Dr. Heddle, from observations in Fife, concluded that the altered blocks in the tuff there must have been exposed to a temperature of between 660° and 900° Fahr.[2]

Among the numerous vents of Central Scotland, pieces of fine stratified tuff not infrequently appear in the agglomerates. This fact, coupled with the common occurrence of a tumultuous, fractured, and highly-inclined bedding of the tuff with a dip towards the centre of

[1] Scrope, 'Geology and Extinct Volcanoes of Central France,' 2nd edition, p. 68. See E. Reyer, *Jahrb. Geol. Reichsanst.* xxix. (1879), p. 463; and *ante*, p. 329, note 2; A. G. *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 161. [2] *Trans. Roy. Soc. Edin.* xxviii. p. 487.

the neck (Figs. 326, 327), appears to show that the pipes were partly filled up by the subsidence of the tuff consolidated in beds within the crater and at the upper part of the funnel. Further indication of the probable subaerial character of the tuff is furnished by abundant enclosed chips of wood, which may have belonged to trees or brushwood that grew upon the slopes of the cones. These fragments were probably entombed in the tuff while they were still green and full of sap, for they are invariably encrusted with crystalline calcite, which was introduced by infiltrating water, and deposited round them in the interspace left between them and the enclosing matrix after they had dried.[1]

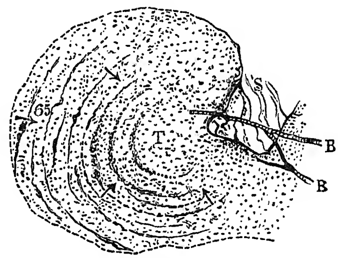

Fig. 327.—Plan of Neck, on shore, at Elie, Fife.

T, tuff; the arrows marking the inward dip; S, sandstones through which the Neck has been blown open; B B, basalt dykes

It is common to find among necks of tuff numerous dykes and veins of lava which, ascending through the tuff, are usually confined to it, though occasionally they penetrate the surrounding strata. They are often beautifully columnar, the columns diverging from the sides of the dykes and being frequently curved.

Proofs of subsidence round the sides of vents may often be observed. Stratified rocks, through which a volcanic funnel had been opened, commonly dip into it all round, and may even be seen on edge, as if they had been subsequently dragged down by the subsidence of the materials in the vent.[2] The fact of subsidence beneath modern volcanic cones has already been referred to (p. 310).

A remarkable region for the abundance of its volcanic necks and the clearness of the sections in which their structure and their relations to the surrounding rocks are exposed, lies in the eastern part of the county of Fife, Scotland, to which allusion has already been made. In a space of about 12 miles in length by from 6 to 8 in breadth no fewer than eighty vents have been detected, and others may still be concealed under superficial deposits. They pierce the various subdivisions of the Carboniferous system, and are thus probably post-Carboniferous. They not improbably belong to the same volcanic period with the necks and andesite lavas of Ayrshire and Nithsdale, which have been regarded as Permian. One great feature of interest in regard to them is the way in which they have been dissected by the sea along the shore. Every detail of their internal organisation can thus be studied, and an idea can be formed of the tectonic arrangement of a volcanic vent such as cannot be obtained from any modern volcano. Some of the foregoing illustrations are taken from these Fife necks (Figs. 325, 326, and 327).[3]

On the continent of Europe the detached bosses of peperite in Auvergne not

[1] See the "Geology of East Fife" (*Mem. Geol. Surv.*), 1902, p. 274.

[2] *Trans. Roy. Soc. Edin.* xxix. p. 469. For an excellent example from New Zealand, see Heaphy, *Q. J. Geol. Soc.* 1860, p. 245.

[3] These necks were first described in my Memoir, already cited from *Trans. Roy. Soc. Edin.* xxix. p. 437; but I have recently given a much fuller account of them, with numerous diagrams and plates, in the Geological Survey Memoir on the Geology of East Fife, above cited.

improbably mark the sites of some of the oldest and most denuded volcanic vents in that district (p. 175). A remarkable region for necks is that of the Swabian Alb of Würtemburg, where 125 separate examples have been found. They are filled with tuff, but

Fig. 328.—Section across the Binn of Burntisland, Fife, showing a central Neck with surrounding lavas and tuffs. 1, Sandstones; 2, Limestone; 3, Shales, &c.; *b b* Interstratified basalts; *t t*, Bedded tuffs, &c.; T, Tuff of the great neck of the Binn; B, Basalt veins.

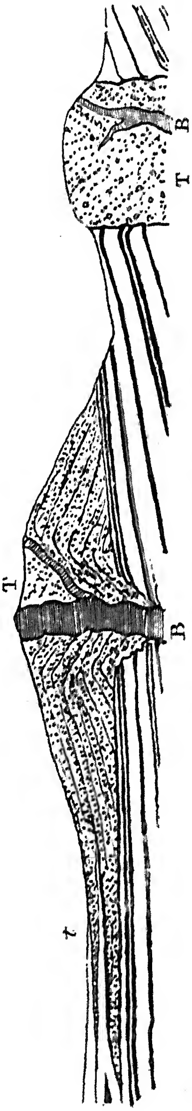

Fig. 329.—Section across the Saline Hills, Fife. T, Tuff of necks; *t*, Continuation of tuff of cone interstratified with the contemporaneously formed sedimentary strata; B, Basalt. The thick parallel lines are coal-seams, which have been charred round the [illegible] (Knock Hill), while they can be [illegible] under the [illegible] of Saline Hill.

sometimes with basalt, and have risen vertically through different members of the Jurassic system without apparently the assistance of any pre-existing faults or fissures. They have been elaborately described by Professor Branco.[1]

[1] "Schwabens 125 Vulkan-Embryonen und deren tufferfüllte Ausbruchsröhren—das grösste Gebiet ehemaliger Maare auf der Erde," Tübingen, 1894.

Effects on Contiguous Rocks.—The strata round a neck are usually somewhat hardened. Sandstones have acquired a vitreous lustre; argillaceous beds have been indurated into porcellanite; coal-seams have been fused, blistered, burnt, and rendered unworkable. The coal-workings in Fife and Ayrshire have revealed many interesting examples of these changes, which may be partly due to the heat of the ascending column of molten rock or ejected fragments, partly to the rise of heated vapours, even for a long time subsequently to the volcanic explosions. Proofs of metamorphism, probably due to the latter cause, may sometimes be seen within the area of the neck itself. Where the altered materials are of a fragmentary character, the nature and amount of this change can best be estimated. What was probably originally a general matrix of volcanic dust has been converted into an indurated more or less crystalline mass, through which the dispersed blocks, though likewise intensely altered, are still recognisable. Such blocks as, from the nature of their substance, must have offered most resistance to change—pieces of sandstone or quartz, for example—stand out prominently in the altered mass, though even they have undergone more or less modification, the sandstone being converted into vitreous quartzite.

Section ii. Interstratified, Volcanic, or Contemporaneous Phase of Eruptivity.

The phenomena of volcanic action, together with the products and structure of volcanoes having been already discussed in Book III. Part I., we have now only to consider those features of the subject which distinguish the volcanic rocks of former ages, which enable us to follow the progress of volcanism in the past and which fix the dates of the successive eruptions. It is evident that, on the whole, the masses of volcanic material which have been erupted to the surface must agree in lithological characters with rocks already described, which have been extravasated by volcanic efforts without quite reaching the surface. Yet they have some well-marked general characters, of which the most important may be thus stated. (1) They occur as beds or sheets, sometimes lava-form, sometimes of fragmental materials, which conform to the bedding of the strata among which they are intercalated. (2) They do not break into or alter overlying strata, though they have sometimes ploughed up and involved portions of the sediment underneath them and over which they flowed. (3) The upper and under surfaces of the lava-beds present commonly a scoriaceous or vesicular character, which may even be found extending throughout the whole of a sheet. (4) Fragments of these upper surfaces not unusually occur in the immediately overlying strata. (5) Beds of tuff are frequently interstratified with sheets of lava, but may also occur by themselves, intercalated among ordinary sedimentary strata.

A record of the feeblest display of contemporaneous volcanic energy in any old group of rocks is furnished by a band of interstratified tuff, marking a single volcanic eruption. A succession of such bands indicates

a series of similar discharges, and every intermediate stage may be illustrated by examples up to a mass of lavas and tuffs many thousands of feet in thickness intercalated among sedimentary deposits.

In the investigation of former volcanic action the detection of true volcanic tuff is of fundamental importance. While the observer may be in doubt whether a particular bed of lava has been poured out at the surface as a true flow, or has consolidated at some depth as a sill, and, therefore, whether or not it furnishes evidence of an actual volcanic outbreak at the locality, he is not liable to the same uncertainty among the fragmental eruptive rocks. Putting aside the occasional brecciated structure seen along the edges of plutonic intrusive masses, he may regard all the truly fragmental igneous rocks as proofs of volcanic action having been manifested at the surface. The agglomerate found in a volcanic neck could not have been formed unless the vapours in the vent had been able to find their way to the surface, and in so doing to blow into fragments the rocks on the site of the vent as well as the upper part of the ascending lava-column.[1] Wherever, therefore, a bed or series of beds of tuff occurs interstratified in geological formations, it points to contemporaneous volcanic eruptions. Hence the value of these rocks in interpreting the volcanic annals of a region.

The fragmentary ejections from a volcano or a cooling lava-stream vary from the coarsest agglomerate to the finest tuff, the coarser materials being commonly found nearest to the source of discharge. They naturally differ in composition, according to the nature of the lavas with which they are associated and from which they have been derived. Where the lavas are basic or acid, so likewise the tuffs are expected to be, though, as has been above stated (p. 712), instances have been observed where, owing to the presence of a heterogeneous magma or of two distinct magmas, showers of acid fragments have alternated with the outflow of intermediate or even basic lavas. The fragmentary matter ejected from volcanic vents has fallen partly back into the funnels of discharge, partly over the surrounding area. It is apt, therefore, to be more or less mingled with ordinary sedimentary detritus. We find it, indeed, passing insensibly into sandstone, shale, limestone, and other strata. Alternations of gravelly *peperino*-like tuff with a very fine-grained "ash" may frequently be observed. Large blocks of lava-form rock, as well as of the strata through which the volcanic explosions have taken place, occur in the tuffs of most old volcanic districts. Occasionally such ejected blocks as well as bombs, derived from the expulsion of molten material, are found among the fine shales and other strata, the lamination of which is bent down round them in such a way as to show that the stones fell with considerable force into the still soft and yielding silt or clay (Fig. 330).[2]

Volcanic tuffs and conglomerates occur in interstratified beds without

[1] It is conceivable, as already stated, that where a mass of lava was injected into a subterranean cavern, fragmentary discharges might take place and partly fill that cavity; but such exceptional cases are probably extremely rare.

[2] See *Geol. Mag.* i. (1864), p. 22.

any accompanying lava, much more commonly than do interstratified sheets of lava, without beds of tuff; just as in recent volcanic districts, it is more usual to find cones of ashes or cinders without lava, than lava-sheets without an accompaniment of ashes. Masses of fine or gravelly tuff, several hundreds of feet in thickness, without the intervention of any lava-bed, may be observed in the volcanic districts of the Old Red Sandstone and Carboniferous systems in Scotland. These furnish evidence of long-continued volcanic action, during which fragmentary materials were showered out over the water-basins, mingled with little or no ordinary

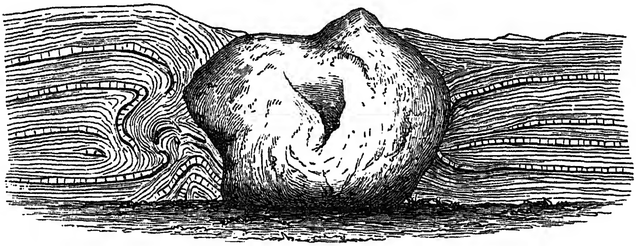

Fig. 330.—Ejected volcanic block (12 × 15 × 17 inches) in Lower Carboniferous Shales, Pettycur, Fife.

sediment. On the other hand, in these same areas, thin seams of tuff interlaminated with sandstone, shale, or limestone, afford indications of feeble intermittent volcanic explosions, whereby light showers of dust were discharged, which settled down quietly amidst the sand, mud, or limestone accumulating at the time. Under these latter circumstances, tuffs often become fossiliferous; they enclose the remains of such plants and animals as might be lying on the lake-bottom or sea-floor over which the showers of volcanic dust fell, and thus they form a connecting link between aqueous and igneous rocks.

As illustrations of the nature of the stratigraphical evidence for former conditions of volcanic activity, furnished by intercalations of tuff, some examples from the Carboniferous formations of Britain may here be given. In Fig. 331, from the Calciferous Sandstone series of Linlithgowshire, the successive conditions of the floor of a lagoon are presented to our view. At the bottom of the section lies a black shale (1) of the usual carbonaceous type, with remains of terrestrial plants. It is covered by a bed of nodular bluish-grey tuff (2), containing black shale fragments, whence we may infer that the underlying or some similar shale was blown out from the site of the vent that furnished this dust and gravel. A second black shale (3) is succeeded by a second thin band of fine pale yellowish tuff (4). Black shale (5) again supervenes, containing rounded fragments of tuff, perhaps lapilli intermittently ejected from the neighbouring vent, and passing up into a layer of tuff (6), which marks how the volcanic activity gradually increased again. It is evident that, but for the proximity of an active

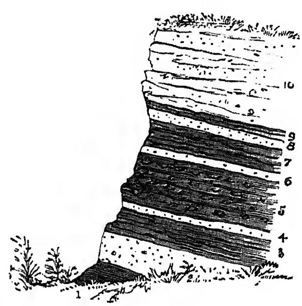

Fig. 331.—Section of interstratifications of tuff and shale, old Quarry, Wester Ochiltree, Linlithgowshire (Lower Carboniferous).

volcanic vent, there would have been a continuous deposit of black mud, the conditions of sedimentation having remained unchanged. In the next stratum of shale (7), thin seams and nodules of clay-ironstone accumulated round decomposing organic remains on the muddy bottom. A brief volcanic explosion is marked by the thin tuff-bed (8), after which the old conditions of deposit continued, the bottom of the water, as the shale (9) shows, being crowded with ostracod crustaceans, while fishes, whose coprolites have been left in the mud, haunted the locality. At last, however, a much more powerful and prolonged volcanic explosion took place. A coarse agglomerate or tuff (10), with blocks sometimes nearly a foot in diameter, was then thrown out and overspread the lagoon.

A scene of a somewhat different kind is revealed by the section drawn in Fig. 332,

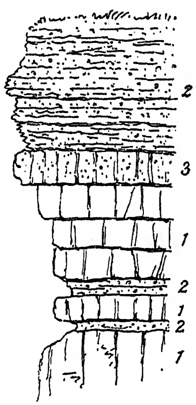

Fig. 332.—Section in quarry of Carboniferous Limestone, Limerick.
1, Limestone; 2, Calcareous tuff; 3, Ashy limestone or highly calcareous tuff.

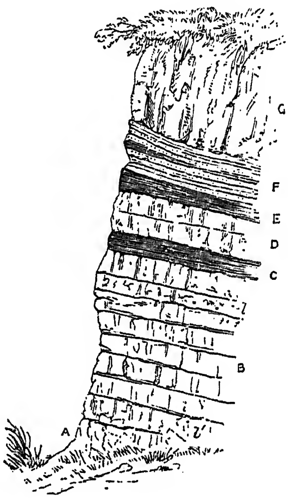

Fig. 333.—Section in Wardlaw Quarry, Linlithgowshire.

which represents a thickness of about 15 feet of strata. The lowest rock visible is a black, tolerably pure limestone, formed of organisms which lived on the sea-floor. As it is followed upward it is seen to be interleaved with thin partings of fine greenish calcareous tuff, each of which marks a separate eruption from some neighbouring volcanic vent. The intervals between the successive explosions must have been long enough, not only to allow the water to become clear, but to permit the calcareous organisms once more to spread over the bottom and form a layer of limestone. Half-way up the section the volcanic material rapidly increases in amount until it takes the place of the limestone, though its calcareous composition shows that some of the organisms still mingled their remains with the volcanic dust that had buried their predecessors.[1]

As the presence of true volcanic tuff proves that molten rock has risen in a vent, whence it has been blown out to the surface in the form of dust and lapilli, we may always be prepared to find evidence that it also flowed out in streams of lava. In Fig. 333, for example, a record is supplied of the outflow of two sheets of lava over the floor of the sea in which the Carboniferous limestone was deposited. The interval of time between

[1] 'Ancient Volcanoes of Great Britain,' ii. p. 44.

their respective eruptions is here represented by about 20 feet of sediments, consisting mainly of organically-derived limestone with some intercalations of black mud and grey sand. At the bottom of the section, a pale amygdaloidal, somewhat altered form of basalt (A) marks the upper surface of one of the submarine lavas of the period. Directly over it comes a bed of limestone (B) 15 feet thick, the lower layers of which are made up of a dense growth of the thin-stemmed coral, *Lithostrotion irregulare*, which overspread the hardened lava. The next stratum is a band of dark shale (C), about 2 feet thick, followed by about the same thickness of an impure limestone with shale seams. The conditions for coral growth were evidently not favourable; for the deposit of this argillaceous limestone was arrested by the precipitation of a dark mud, now to be seen in the form of 3 or 4 inches of a black pyritous shale (E), and next by the inroad of a large quantity of a dark sandy mud, and drift vegetation, which has been preserved as a sandy shale (F) containing *Calamites*, *Producti*, ganoid scales, and other traces of the terrestrial and marine life of the time. Finally a sheet of lava, represented by the

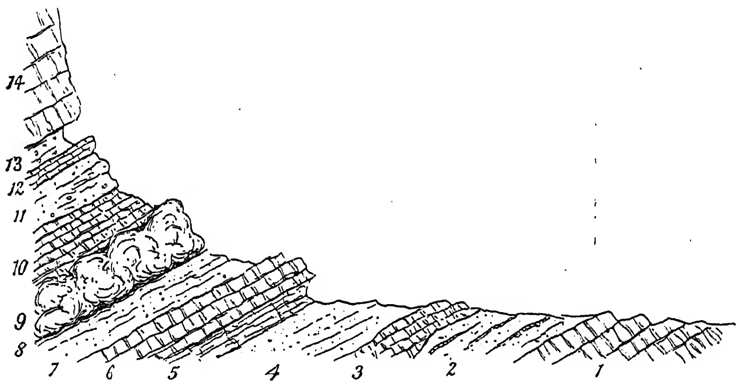

Fig. 334.—Section of the volcanic group in the Carboniferous Limestone, Middle Hope, mouth of Severn, Somerset.

uppermost amygdaloid (G), overspread the area, and sealed up these records of Palæozoic history.

An example from another portion of the same ancient sea-bottom will serve to show how both tuffs and lavas may be interstratified in a conformable and continuous succession of marine organic limestones. It is taken from the interesting volcanic group near Weston-super-Mare, and represents the whole of that group, here about 100 feet thick, intercalated in the midst of the marine limestones.[1] At the bottom lies the normal highly fossiliferous crinoidal limestone (1), the deposition of which was now interrupted. It becomes impure towards the top, where it is covered with a greenish volcanic tuff (2) about 12 feet thick, including calcareous bands. This tuff marks the beginning of the eruptions which were ushered in with a discharge of ashes and dust. Then came an interval of quiescence, during which the organisms, especially *Productus*, swarmed over the first volcanic deposit, and built up an irregular sheet of thin-bedded limestone (3) three feet thick and upwards. Another eruption now took place, which covered up the shells, crinoids and corals, and formed the group of tuffs (4), though some of the organisms struggled on and formed lenticular seams of limestone among the volcanic sediment. They once more were able to gather into thicker

[1] A. Strahan and A. G. in *Summary of Progress of Geological Survey* for 1898, pp. 104-111.

continuous seams of limestone (5). The limestone (6) is crowded with their remains, and as it has a thickness of 15 feet, it marks a pause of some duration in the volcanic activity. This interval was at last brought to an end by a renewed and more energetic manifestation of subterranean energy. First came a series of vigorous discharges of fine dust and stones, which eventually accumulated to a depth of from 12 to 14 feet of tuff (7). A thin layer of chert (8) lies at the top of the volcanic sediment, and is immediately overlain with a dull green somewhat decomposing vesicular olivine-basalt (9), 12 to 14 feet thick, displaying marked ellipsoidal structure, and presenting a rugged scoriaceous upper surface. This lava marks the culmination of the volcanic episode in the district. It was followed by a time of comparative quiescence, during which occasional showers

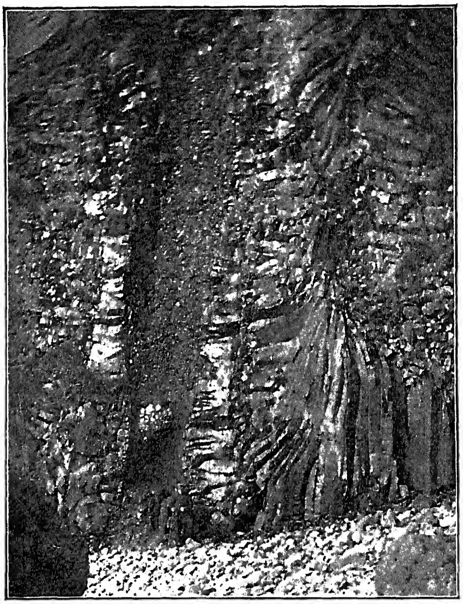

Fig. 335.—Erect coniferous tree-trunk surrounded by and buried under Tertiary basalt, Gribon, Isle of Mull. ('Scenery of Scotland,' 3rd edition, p. 142.)

of fine volcanic dust were discharged, traces of which are preserved as thin partings in the nine feet of highly fossiliferous limestone (10) which overlies the basalt, and has filled up all the irregularities of its surface. A recrudescence of volcanic activity is indicated by the band of green tuff (11) about nine feet thick, but the discharges were not so continuous or violent as wholly to kill off the calcareous organisms on the sea-bottom, for their remains have been aggregated into lenticular seams and nodules among the volcanic sediment. The red limestone (12) about three feet thick shows by its thin leaves of tuff that feeble discharges of dust were still taking place. These indications of volcanic action become still feebler in the overlying reddish nodular limestone (13), also about three feet thick, above which comes once more normal thick limestone wholly made of organic remains, like that below the volcanic group.

In the case of subaerial eruptions we may expect to meet with occasional intercalations of lacustrine or fluviatile sediment containing the remains of a land flora or fauna. The Tertiary volcanic series of Central France presents many instructive and classic examples of this association. We there find the fine tuffs alternating in thin laminæ with the fresh-water limestones, and delicately filling the cavities of the shells of pond-

snails. In the west of Scotland the Tertiary basalt-plateaux contain interesting examples of river-channels filled with gravel, and sometimes containing drift-wood, which have been buried under streams of lava. In at least one instance a coniferous tree with a stem five feet in diameter has been enveloped in the molten rock, and still retains its erect position. The bark and outer part of the wood were charred, and the upper part of the trunk had decayed, leaving an empty cylinder in the basalt, into which rubbish was washed from the ground above, before the next outflow of lava buried it. As shown in Fig. 335, the columns of the basalt diverge from the sides of the tree, which formed the cooling surface whence the contraction started.

While the underground course of a protruded mass of molten igneous rock has widely varied according to the shape of the channel through which it proceeded and in which, as in a mould, it solidified, the behaviour

Fig. 336. *Sandstone filling rents in the surface of an interbedded sheet or flow of porphyrite, which is covered with a bed of conglomerate. Coast of Kincardineshire.*
The rents have been filled in with sand before the eruption of the next flow.

of the rock, once poured out at the surface, is more uniform. The erupted lava rolls along, varying in thickness and other minor characters, according to its viscosity, the angle of slope and the irregularities of the topography over which it flows. It forms a rough, lenticular bed or sheet. A comparison of such a bed with one of the intrusive sheets already described shows that in several important lithological characters they differ from each other. An intrusive sheet is closest in grain near its upper and under surfaces; a contemporaneous bed or true lava-flow, on the contrary, is there usually most open and scoriaceous. In the one case, we comparatively rarely see vesicles or amygdales, and when they do occur they are usually small in size, and more or less uniformly distributed along certain bands or lines. In the lavas, on the other hand, such vesicles commonly abound, and present wide variations in size, shape, and distribution. However rough the upper surface of an inter-stratified sheet may be, it never sends out veins into, nor encloses portions of the superincumbent rocks, which, however, sometimes contain portions of it, and wrap round its hummocky irregularities. Occasionally it may

be observed to be full of rents, which have been filled up with sandstone or other sedimentary material. These rents were formed while the lava was cooling, and sand was subsequently washed into them. Examples of this structure abound among the andesite lavas of the volcanic tracts of the Scottish Lower Old Red Sandstone (Fig. 336).[1]

The amygdaloidal cavities throughout an interstratified sheet, but more especially at the top, often present an elongated form, and are even pulled out into tube-like hollows in one general direction, which was obviously the line of movement of the yet viscous mass (pp. 134, 306). Some kinds of rock, which have appeared as superficial lava-flows, have assumed a system of columnar jointing. Basalt, in particular, is distinguished by the frequency and perfection of its columns. The Giants' Causeway, the cliffs of Staffa, of Ardtun in Mull, and of Loch Staffin in Skye, the Orgues d'Expailly in Auvergne, and the Kirschberg of Fulda are well-known examples. Andesite, rhyolite, obsidian, pitchstone and other effusive rocks likewise occur occasionally in columnar forms. Some basic lavas, during their flow, have broken up into rounded, elliptical or pillow-shaped masses of all sizes, from a few inches to several feet or even yards in diameter (pp. 136, 306). These blocks often present lines of small amygdales close to their edges, the centre being sometimes marked by larger and more irregularly shaped cavities. The interspaces between the ellipsoids were usually filled with some sedimentary deposit, which among the Palæozoic examples is not infrequently chert containing *Radiolaria*, but it may be limestone, shale, ironstone, volcanic tuff or other material. The origin of these rounded blocks has been ascribed to the sudden disruption and chilling of lava that has flowed into a lake, river, or the sea.[2]

Lenticular sheets or groups of sheets of lava, usually of limited extent and with associated bands of tuff, form the more frequent type among Palæozoic and Secondary formations. A single interbedded sheet may occasionally be found intercalated between ordinary sedimentary strata, without any other volcanic accompaniment. But this is unusual. In the great majority of cases, several sheets occur together, with accompanying bands of contemporaneous tuff, and they may be piled up into accumulations thousands of feet in thickness, their geological age being generally ascertainable from the organic remains associated with them or with the conformable strata immediately below or above them.

Interbedded (and also intrusive) sheets have shared in all the subse-

[1] See 'Ancient Volcanoes of Great Britain,' i. pp. 283, 333, where a number of examples are figured, also "Geology of East Fife," *Mem. Geol. Surv.* Compare the mud-enclosures described by Professor B. K. Emerson, in the Triassic Trap of New England, and attributed by him to the influence of strong convection currents, whereby mud was rapidly diffused over and under lava that flowed into water. *Bull. Geol. Soc. Amer.* viii. (1897), p. 59.

[2] For descriptions of the ellipsoidal structure of lavas, see G. Platania, in H. Johnston-Lavis' 'South Italian Volcanoes,' Naples, 1891, p. 41, and Plate vii.; J. J. H. Teall and H. Fox, *Q. J. G. S.* xlix. (1893), p. 211; J. J. H. Teall, *Trans. Roy. Geol. Soc. Cornwall*, 1894, p. 3; F. L. Ransome, *Bull. Geol. Univers. California*, No. 7 (1894); A. G. 'Ancient Volcanoes of Great Britain,' i. pp. 25, 184, 193; T. Morgan Clements, Monograph xxxvi. *U.S. Geol. Surv.* 1899, p. 112.

quent curvature and faulting of the formations among which they lie. This relation is well seen in the "toadstone" or sheets of dolerite, basalt, and tuff associated with the Carboniferous Limestone of Derbyshire (Fig. 337).[1]

Fig. 337. Section of intercalated lavas and tuffs ("toadstone") in Carboniferous Limestone, Derbyshire (B). a a, "Toadstone," in two beds; b b, Limestones; c, Millstone grit; f f, Faults.

In such abundantly volcanic districts as Central Scotland, the necks or vents of eruption (Figs. 328, 389) may frequently be detected among the lavas which proceeded from them. The thickness of an interbedded sheet varies for different kinds of lava. As a rule, the more acid rocks are in thicker beds than the more basic. Some of the thinnest and most persistent sheets may be observed among the basalts, where a thickness of not more than 12 or 15 feet for each sheet is not uncommon. Both individual sheets and groups of sheets have commonly a markedly lenticular character. They usually thicken in a particular direction, probably that from which they flowed. On the other hand, beds of tolerably uniform thickness and flatness of surface may be found; among the basalts, more particularly, the same sheet may be traceable for miles, with remarkable regularity of thickness and parallelism between its upper and under surfaces (p. 763). The andesites and trachytic and rhyolitic lavas are more irregular in thickness and form of surface. The domite of Auvergne has formed domes without spreading out into sheets.

Abundant examples of thick intercalated volcanic groups may be studied among the Palæozoic and Tertiary formations of Western Europe, and nowhere on a larger scale than in the British Isles. The Cambrian lavas and tuffs of Pembrokeshire, and those of Arenig and Bala age in North Wales, the Lake District, the south of Scotland, and the south-east of Ireland form a notable record of volcanic activity in older Palæozoic time. They were succeeded by the great outpourings of the Old Red Sandstone, Devonian, Carboniferous, and Permian volcanoes. But the volcanic energy gradually diminished until the last Permian eruptions gave rise to groups of small tuff-cones, like those of Auvergne, never discharging floods of lava like those of earlier periods, and probably in most cases emitting only showers of ashes and stones.[2] There appears to have been a complete quiescence of volcanic activity during the whole of the Mesozoic ages in Britain. But the subterranean fires were rekindled in older Tertiary time, and gave forth the great basalt sheets of Antrim and the Inner Hebrides.

On the continent of Europe a similar long record of volcanic action is found, with a corresponding Mesozoic quiescence. Cambrian, Silurian, Devonian, Carboniferous, and Permian volcanic rocks have been found in France. The Permian volcanic rocks of Germany have long been well known. In the Tyrol occur extensive sheets of quartz-porphyry of Triassic or older date, together with associated tuffs.

Some of the most enormous accumulations of ejected volcanic material are found among the records of Tertiary time in the western parts of North America. Thus in the Absaroka range in Wyoming the following sequence of volcanic ejections has been established, the whole amounting to 11,000 feet.[3]

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[1] See Section 18 of *Horiz. Sect. Geol. Surv. Great Britain.*

[2] 'Ancient Volcanoes of Great Britain,' where the British volcanic history is fully described.

[3] Mr. Hague, 'Absaroka Folio,' *U.S. G.S.* Presidential Address to Geol. Soc. Washington, 1898. This section furnishes another example of alternating basic and acid ejections.

Late Basalt flows	300 feet
Late Basic Breccia, alternations of coarse and fine fragmental material, pointing to a prolonged succession of eruptions . .	2500 ,,
Late Acid Breccia, composed mainly of andesite detritus, the result of many successive explosions	2000 ,,
Early Basalt flows in sheets from 5 to 50 feet in thickness . .	1200 ,,
Early Basic Breccia, coarse and fine, with intercalated sheets of basalt which increase in number and thickness towards the top .	4000 ,,
Early Acid Breccia, coarse and fine material irregularly heaped together, with some beds of silt and mud	1000 ,,

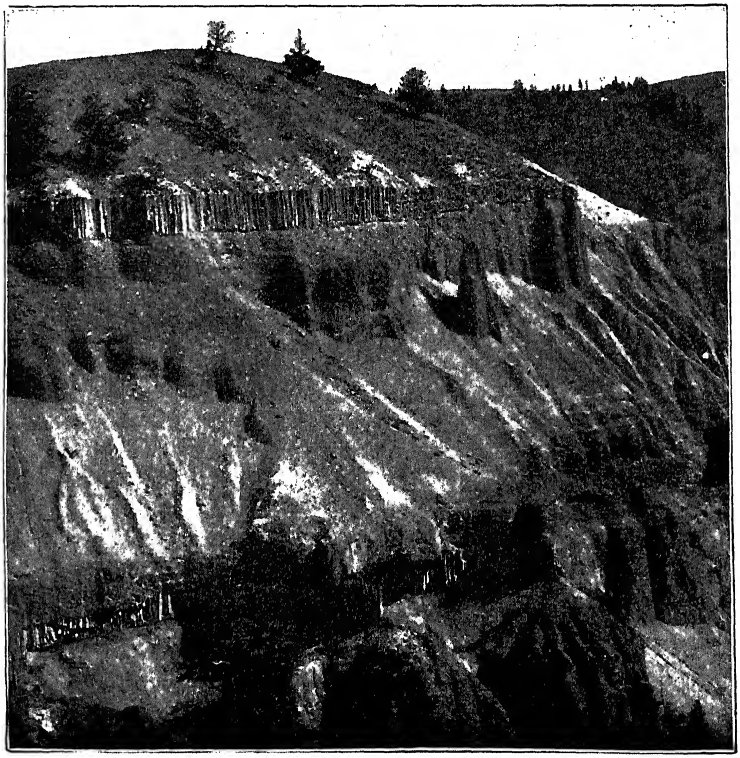

Fig. 338.—Succession of Volcanic conglomerates and lava-sheets, Cañon of Yellowstone River. Photograph by Mr. C. D. Walcott, U. S. Geol. Survey.

Some of these breccias are crowded with erect and prostrate fossil trees, which mark successive forest-growths that were overwhelmed and buried under the enormous amount of fragmentary material discharged from the neighbouring vents.

To the west of the Absaroka range lies the Yellowstone National Park, where the Yellowstone River has cut vast ravines out of the volcanic series, displaying on a grand scale a succession of breccias or conglomerates and intercalated lavas. The general topography of the cañon, as influenced by the difference in weathering of the two kinds of material, is represented in Fig. 338, the hard columnar lavas forming prominent bars.

Traces of three types of volcanoes may be recognised among the volcanic rocks interstratified in the various geological formations.

1. The Vesuvian type—consisting of lavas and tuffs which have come mainly from one central orifice. Here the rocks rapidly diminish in thickness away from their point of origin, and hence form lenticular intercalations among the sedimentary strata with which they are associated. Thus in Linlithgowshire, the mass of lavas and tuffs above referred to (Figs. 331, 333) reaches a collective thickness of probably 2000 feet in the Carboniferous Limestone series, but dies out so rapidly that within a distance of about ten miles it has dwindled down to a single sheet of lava less than 50 feet thick. Still more rapid attenuation is observable among the older volcanic accumulations of Central Scotland and North Wales. We have only to reflect on what would be the probable structure displayed by Vesuvius if it had been buried under some sedimentary accumulation, and had afterwards been laid bare to the roots by prolonged denudation, in order to be able to understand the condition in which ancient representatives of the same type may be expected to appear. (Compare Figs. 293, 294.)

2. The Plateau type consists of sheets of lava and tuff which instead of accumulating round a main centre of discharge have spread out over wide areas, sometimes amounting to thousands of square miles. These materials have sometimes come directly out of fissures opened at the surface (fissure-eruptions, p. 342), sometimes out of vents which may be crowded closely together. In this type the lavas usually largely predominate over the fragmental discharges. The more basic lavas, especially those of the basalt family, have most frequently assumed this form.

The fragmentary plateaux of the British Islands, the Faroe Islands and Iceland; those of the Indian Deccan and of Abyssinia, and the more recent basalt floods which have closed the eventful history of volcanic action in North America, are notable illustrations of this type of structure. Beds of tuff, conglomerate, gravel, clay, shale, or other stratified intercalations occasionally separate the sheets of basalt. Layers of lacustrine clays, sometimes full of leaves, and even with sufficiently thick masses of vegetation to form bands of lignite or coal, may also here and there be detected Occasional prostrate or even erect trees may be observed enclosed in the lava (Fig. 335). But marine intercalcations are rare or absent. There can be no doubt that these widely extended sheets of basalt were in the main subaerial outpourings, and that in the hollows of their hardened surfaces lay lakes and smaller pools of water in which the interstratified sedimentary materials were laid down. The singular persistence of the basalt beds has often been noticed. The same sheet may be followed for several miles along the magnificent cliffs of Skye and Mull. Mr. Clarence King believes that single sheets of basalt in the Snake River lava-field of Idaho may have flowed for 50 or 60 miles.[1] The basalts, however, so exactly resemble each other that the eye may be deceived unless it can follow a band without any interruption of continuity.

Next to the basalts, perhaps, come the andesites as plateau-builders. Conspicuous examples of the way in which they have been piled over each other to a depth of many hundred feet and over areas of hundreds of square miles may be seen in Central and Southern Scotland, where the Old Red Sandstone (hills of Lorne) and Carboniferous

[1] 'Geological Exploration of 40th Parallel,' i. p. 593. See also C. E. Dutton, *Nature*, 27th November 1884. *6th Ann. Rep. U.S. Geol. Surv.* 1884-85, p. 181, and *4th Ann. Rep.* same Survey, 1882-83, p. 85.

systems (Campsie Fells and hills above Largs), include consecutive sheets of different andesites and diabases that rise into long terraced tablelands. The regularity of thickness and parallelism of these sheets form conspicuous features in the scenery of the districts in which they occur.

3. The Puy type is shown by scattered vents filled with agglomerate or tuff, sometimes also with dykes or plugs of lava. In many cases these vents have not emitted any lava-streams. They mark a comparatively feeble phase of volcanic action. They are sometimes, however, remarkably abundant within a restricted area, as in the tract of East Fife already referred to (p. 751), where at least eighty of them are crowded together within a space of 70 or 80 square miles. The puys of Auvergne, the maare of the Eifel, and the small tuff-cones of the Bay of Naples are familiar examples of late geological age.

Part VIII. Metamorphism, Local and Regional.

The sense in which the terms "metamorphism" and "metamorphic" are to be employed should be precisely defined at the beginning of a discussion of the subject to which they are applied. It is obvious that we have no right to call a rock metamorphic, unless we can (1) distinctly trace it into an unaltered condition, or (2) can show from its internal composition and structure that it has undergone a definite change, or (3) can prove its identity with some other rock whose metamorphic character has been satisfactorily established. At the outset, it may be remarked that, in a certain sense, all or nearly all rocks may be said to have been "metamorphosed," since it is exceptional to find any, not of very modern date, which do not show, when closely examined, proofs of having been hardened by the pressure of superincumbent rock, or altered by the action of percolating water or other daily acting agent of change. Even a solid crystalline mass, which, when viewed on a fresh fracture with a good lens, seems to consist of unchanged crystalline particles, will often betray under the microscope unmistakable evidence of alteration. And this alteration may go on until the whole internal organisation of the rock, so far at least as we can penetrate into it, has been readjusted, though the external form may still remain such as hardly to indicate the change, or to suggest that any new name should be given to the recomposed rock. Among many igneous rocks, particularly the more basic kinds (diabases, basalts, andesites, diorites, olivine rocks, &c.), alteration of this nature may be studied in all stages.[1]

But mere alteration by decay is not what geologists denote by metamorphism. The term has been, indeed, much too loosely employed; but it is now generally used to express a change in the mineralogical or chemical composition and in the internal structure of rocks, produced at some depth from the surface, either locally, by intruded masses of highly heated material, or regionally, through the operation of mechanical movements, combined with the influence of heat and heated water or vapour.

Metamorphism may consist in, 1st, change of aspect or texture, including induration and other minor phenomena ("contact metamorphism"); or

[1] *Ante*, p. 453, under "Weathering."

2nd, change of form, including all paramorphic transformations, such as the conversion of a pyroxenic into a hornblendic rock, and the alteration of a clastic into a crystalline mass by the crystallization of its original constituents; or 3rd, change of substance, where a chemical (metachemic) change has been superinduced either by the abstraction or addition of one or more ingredients, as in the remarkable contact zones round certain intrusive bosses. It is obvious, however, that each of these three forms of metamorphism may be included in the changes which have been superinduced upon a given mass of rock.[1]

The conditions that appear to be mainly concerned in metamorphism have been already stated (p. 424). It may be added here that these conditions may in different cases be supplied: 1st, by the action of heated subterranean water carrying carbonic acid and mineral solutions, and often under great pressure (pp. 401, 409); 2nd, by the action of hot vapours and gases (pp. 269, 313); 3rd, by mechanical pressure combined with heat, but without internal movement or deformation, such pressure and heat at great depths in the terrestrial crust being enormous; 4th, by mechanical movements, particularly those which have resulted in the crushing and shearing of rocks, and which at great depths must be all the more effective from the vast pressure and high temperature (pp. 400, 411); 5th, by the intrusion of heated eruptive rocks, sometimes containing a large proportion of absorbed water, vapours, or gases (pp. 407, 413); 6th, occasionally and very locally by the combustion of beds of coal. Much will obviously depend on the relations of temperature and pressure under which the rocks are acted on. Mr. Harker has indicated four variations of these relations, which may in different places have existed: (1) low temperature and low pressure (Hydro-metamorphism); (2) high temperature and low pressure (Thermo-metamorphism); (3) low temperature and high pressure (Dynamo-metamorphism); (4) high temperature and high pressure (Plutono-metamorphism).[2]

The term "metamorphism," as originally proposed by Lyell, was

[1] Many terms have been devised to express the character of metamorphic changes. For instance, *metasomatosis*, *metasomatic*, *methylosis*, *methylotic*, and *metachemic* applied to chemical metamorphism or alteration of constitution or substance; *metastasis*, indicating changes of a paramorphic nature; *metacrasis*, denoting such transformations as the conversion of mud into a mass of mica, quartz, and other silicates; *macro-structural* metamorphism, having the external structure (morphology) changed, as where an amorphous condition becomes schistose; *micro-structural*, having the internal structure (histology) wholly changed, with or without a macro-structural alteration; *mineralogical*, having one or more of the component minerals changed, with or without an alteration of the chemical composition of the rock as a whole. See King and Rowney, "An old Chapter of the Geological Record," 1881; Dana, *Amer. Journ. Sci.* xxxii. (1886), p. 69. Bonney, *Quart. Journ. Geol. Soc.* (1886), Address, p. 30 *et seq.* G. H. Williams, *Bull. U.S. Geol. Surv. No.* 62 (1890), p. 43. Various terms have likewise been proposed for metamorphism from the point of view of its cause, as *Dislocation-metamorphism* (Lossen), *Mechanical metamorphism* (Heim and Baltzer), *Friction-metamorphism* (Gosselet), *Dynamical metamorphism* (Rosenbusch), *Heaping-up metamorphism* (*Stauungs M.* Gümbel and Credner), *Pressure metamorphism* (Bonney), and those by Harker, quoted in the next paragraph.

[2] *Geol. Mag.* 1889, p. 16.

applied to rocks having a schistose or foliated structure which were regarded as altered sediments. For many years afterwards it continued to be used in the same sense, and not until comparatively recently did geologists recognise that rocks originally of eruptive origin, but interposed among sedimentary strata, were necessarily affected by the changes which the latter underwent in the processes of metamorphism. It is now well established that igneous rocks no less than aqueous have been metamorphosed, and, as Lossen pointed out, they furnish in some respects even a better starting-point from which to attack the problem of metamorphism, inasmuch as their original definite mineral aggregation, chemical composition and structure furnish a scale by which the subsequent mutations of the rocks may be traced and measured.[1]

It must obviously be often difficult, not infrequently impossible, to determine to what particular combination of conditions the metamorphism of a group of rocks is to be assigned, whether mere pressure, or pressure combined with crushing and deformation, or with a high temperature, or all of these with the co-operation of water and mineralising agents, have been concerned in the change. For convenience of description some kind of classification of the phenomena is required. Accordingly geologists have long been in the habit of recognising among the alterations which can properly be considered metamorphic two broad types. 1st, Contact Metamorphism, where the rocks have been altered by contact with or proximity to some body of eruptive material, and 2nd, Regional Metamorphism, where the alteration cannot be ascribed to any such local cause as the invasion of an intrusive rock, but is so widespread that it must be due to a more general origin, such as conditions of pressure, temperature, mechanical movement, presence of water and mineralising agents affecting extensive tracts of the earth's crust. This arrangement, though convenient, cannot always be satisfactorily made, for although in regional metamorphism a maximum of change is often reached which is hardly equalled in contact-metamorphism, cases are met with where the phenomena of the two types cannot be satisfactorily discriminated. Nevertheless the commonly accepted subdivision is so generally useful that it may well be retained until our knowledge of metamorphism has become more precise and profound than it is at present.

§ i. Contact-Metamorphism.

In this kind of alteration two fundamental conditions have to be considered: 1st, the nature, mass, temperature, and composition of the eruptive rock; and 2nd, the composition and structure of the rocks through which the intrusive material has been injected, and the presence or absence of interstitial water in them. (1) With regard to the first of these conditions, it is obvious that a large intrusion will produce more alteration than a small intrusion of the same rock. The areola of meta-

[1] *Jahrb. Preuss. Geol. Landesanst.* 1884, p. 620. See also, for an early study of the influence of contact-metamorphism on augitic igneous rocks, Allport, *Q. J. G. S.* xxxii. (1876), p. 418.

morphism round a great boss of granite or of diorite will be broader and the metamorphism itself more intense than that round a mere vein or dyke. The constitution of the intrusive rock has been an important factor in the metamorphism. Thus great differences are observable between the nature and amount of this alteration produced by the more basic and the more acid volcanic rocks. The former, such as basalt, possess such extreme fluidity as to be able to penetrate into the cracks of other rocks and catch up fragments of them, which they indurate or even fuse, but without inducing much chemical change. It would appear that mere dry heat produces only a small amount of chemical alteration. The more acid volcanic rocks, on the other hand, such as trachyte, phonolite and rhyolite are viscous or pasty, do not wrap round so closely the rocks which they invade, and seldom melt them, though possessing a temperature considerably higher than that of the basic lavas. But owing probably to the vapours with which they are charged they induce various chemical transformations.[1] Granite has been believed not to furnish examples of the actual fusion of the surrounding or enclosed rocks, though it may have absorbed more or less of them (see, however, p. 776), but it has long been recognised to be accompanied with a more complete transformation of these rocks than any other intrusive material, and this change may be traced to a distance of a mile or more from the line of contact. In this case also, as has been already stated, the presence of pneumatolitic agents—water, alkaline silicates, chlorides and fluorides, with other vapours or solutions, has been largely influential, combined, doubtless, with great pressure, high temperature, and a continuance of these conditions for vast periods of time.

(2) With respect to the influence of the nature and structure of the altered rock upon the metamorphism, it is obvious that such different materials as shale, sandstone, coal, and limestone, will give very different results even if exposed to the same amount and kind of metamorphic energy. The amount of water present in the pores of a rock will likewise largely influence the extent and nature of the alteration. A rock which, if perfectly dry, might undergo little or no change, when heated would be subjected to chemical reactions and mineral re-arrangements by the operation of interstitial water. Much must depend, too, upon the relation between the position of the intrusive mass and the stratification of the rocks affected. As stated on p. 64, heat is conducted four times faster along the planes of stratification than across them, so that an intruded sheet or sill should, other things being equal, produce less alteration than a boss which breaks across the bedding. It will be readily understood, also, that detached portions of a rock which have been caught up and entirely enclosed within an intrusive mass will show usually a more highly altered condition than the peripheral parts of the rock, which have merely presented one side to the invading material.[2]

[1] Professor Lacroix, *Mém. Acad. Sci. Paris*, xxxi. (1894).

[2] Professor Lacroix, in the memoir above cited, has made a particular study of the metamorphism of fragments enclosed in volcanic rocks. On the physical effects of contact-metamorphism, see J. Barrell, *Amer. Journ. Sci.* xiii. (1902), p. 279.

The following examples of the nature of the metamorphism of contact are arranged in progressive order of intensity, beginning with the feeblest change, and ending with results that are quite comparable with the great changes involved in regional metamorphism.

Bleaching is well seen at the surface, where heated volcanic vapours rise through tuffs or lavas and convert them into white clays (p. 313). Decoloration, however, has proceeded also, underneath, along the sides of dykes. Thus in Arran, a zone of decoloration ranging from 5 or 6 to 25 or 30 feet in width, runs in the red sandstone along each side of many of the abundant basalt dykes. This removal of the colouring peroxide may have been effected by the prolonged escape of hot vapours from the cooling lava of the dykes. Had it been due merely to the reducing effect of organic matter in the meteoric water filtering down each side of the dyke, it ought to occur as frequently along joints in which there has been no ascent of igneous matter.

Coloration.—Rocks, particularly shale and sandstone, in contact with intrusive sheets, are sometimes so reddened as to resemble the burnt shale from an ironwork. Every case of reddening along a line of junction between an eruptive and non-eruptive rock must not, however, be set down without examination as an effect of the mere heat of the injected mass, for sometimes the colouring may be due to subsequent oxidation of iron in one or both of the rocks by water percolating along the lines of contact.

Disaggregation.—It is occasionally observable that rocks originally coherent and tough have become friable by contact with eruptive material, as in the case of gneiss and granite in Auvergne, when in contact with the volcanic rocks.

Induration.—Most frequently the reverse of disintegration has been produced, for the rocks along the contact with an intrusive mass have commonly been hardened. Sandstone, for example, is converted into a compact rock which breaks with the lustrous fracture of quartzite. Argillaceous strata are altered into flinty slate, Lydian stone, jasper, or porcellanite. This change may sometimes be produced by mere dry heat, as when clay is baked. But it may also arise from the action of heated water, as is shown where the percentage of silica has been increased by the deposit of a siliceous cement in the interstices of the stone, or by the replacement of some of the mineral substances by silica. Such changes are specially observable round eruptive masses of granite and diabase.[1]

Expulsion of Water.—One effect of the intrusion of molten matter among the ordinary cool rocks of the earth's crust has doubtless often been temporarily to expel their interstitial water. The heat may even have been occasionally sufficient to drive off water of crystallization or of chemical combination. Mr. Sorby mentions that it has been able to

[1] Kayser, on contact-metamorphism around the diabase of the Harz, *Z. D. G. G.* xxii. 103, where analyses showing the high percentage of silica are given. Hawes, *Amer. Journ. Sci.* January 1881. The phenomena of metamorphism round granite are further described below, p. 778 *seq.*

dispel the water present in the minute fluid cavities of quartz in a sandstone invaded by diabase.[1]

Prismatic Structure.—Contact with eruptive rocks has frequently produced a prismatic structure in the contiguous masses. Conspicuous

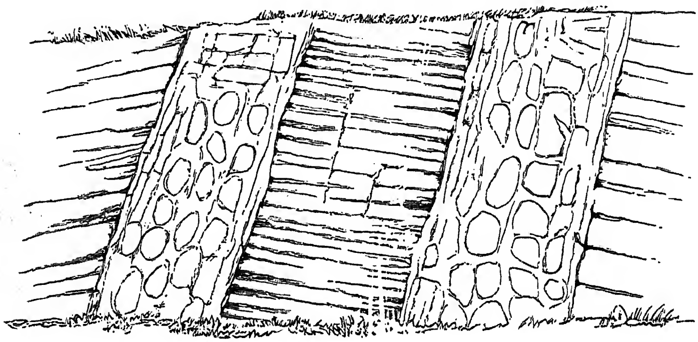

Fig. 339.—Sandstone (*a a*) rendered prismatic by Dolerite (*b b*); Bishopbriggs, Glasgow.

illustrations of this change are displayed in sandstones through which dykes have risen (Fig. 339). Independently of the lines of stratification, polygonal prisms, six inches or more in diameter, and several feet in length, starting from the face of the dyke, have been developed in the sandstone.[2]

Some of the most perfect examples of superinduced prisms may occasionally be noticed in seams of coal which, from offering least resistance in a group of strata, have been more especially apt to be invaded by intrusive igneous rocks. In the Scottish coal-fields, sheets of basalt have been forced along the surfaces of coal-seams, and even along their centre. The coal in these cases is sometimes beautifully columnar, its slender hexagonal and pentagonal prisms, like rows of stout pencils, diverging from the surface of the intrusive sill[3] (Fig. 340). The basalt, on the other hand, has been changed into a kind of clay (*postea*, p. 775).

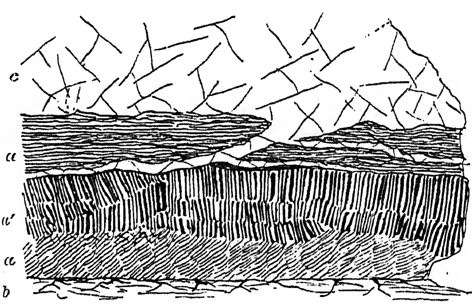

Fig. 340.—Coal-seam (*a a*) lying on fireclay (*b*) and made columnar (*a′*) by a sill (*c*) of Basalt, Shore, Saltcoats, Ayrshire.

[1] *Q. J. G. S.* 1880. *Ante*, p. 735.

[2] Sandstone altered by basalt, melaphyre, or allied rock, Wildenstein, near Büdingen, Upper Hesse; Schöberle, near Kriebitz, Bohemia; Johnsdorf, near Zittau, Saxony (the Quader-sandstone of Gorischstein, in Saxon Switzerland, is beautifully columnar; W. Keeping, *Geol. Mag.* 1879, p. 437); Bishopbriggs, near Glasgow (Fig. 339).

[3] Coal and lignite, with their accompanying clays, altered by basalt, diabase, melaphyre, &c., Ayrshire, Scotland (Fig. 340); St. Saturnin, Auvergne; Meissner, Hesse Cassel; Ettingshausen, Vogelsgebirge; Sulzbach, Upper Palatinate of Bavaria; Fünfkirchen, Hungary: by trachyte, Commentary, Central France; by phonolite, Northern Bavaria.

Other examples of the production of this structure have been described in dolomite altered by quartz-porphyry (Campiglia, Tuscany); fresh-water limestone altered by basalt (Gergovia, Auvergne); basalt-tuff and granite altered by basalt[1] (Mt. Saint-Michel, Le Puy).

Calcination, Melting, Coking.[2]—By the great heat of erupted masses, more especially of basalt and its allies, rocks have been calcined and partially or completely melted. In some, the matrix or some of the component minerals have been melted; in others the whole rock has been fused. Among granite fragments ejected with the slags of old volcanic vents in Auvergne, some present no trace of alteration, others are burnt as if they had been in a furnace, or are partially melted so as to look like slags, their component minerals, however, remaining distinct. In the Eifel volcanic region, the fragments of mica-schist and gneiss ejected with the volcanic detritus have sometimes a crust or glaze of glass. Sandstones, though most frequently baked into a compact quartzite, are sometimes changed into an enamel-like mass in which, when the rock contains an argillaceous or calcareous matrix with dispersed quartz-grains, the infusible quartz may be recognised.

In Hesse and Thuringerwald, Zirkel has described sandstones altered by contact with basalt, where the quartz-grains are enveloped in a vitreous matrix, in which abundant microscopic microlites occur, and present in their arrangement evidence of a fluxion-structure. This glassy constituent probably represents the argillaceous and other materials in which the quartz-grains were originally imbedded, and which has been fused and made to flow by the heat of the basalt.[3] According to Bunsen's observations, volcanic tuff and phonolite have sometimes been melted on the sides of the dolerite dykes which traverse them, so as to present the aspect of pitchstone or obsidian.[4] Complete fusion, fluxion-structure, and microscopic crystallites, resembling those of true igneous rocks, may thus be produced in sedimentary rocks by contact-metamorphism.

The effects of eruptive materials upon carbonaceous beds, and particularly upon coal-seams, are among the most conspicuous examples of this kind of alteration. The effects vary considerably, according to the bulk and nature of the eruptive sheet, the thickness, composition, and structure of the coal-seam, and probably other causes. In some cases, the coal has been made prismatic, as above described. More often it has been fused and has acquired a blistered or vesicular texture, the gas cavities being either empty or filled with some infiltrated mineral, especially calcite (east of Fife). The most frequent change is the conver-

[1] Naumann, 'Geognosie,' i. p. 737.

[2] It is worthy of observation that changes of the kind here referred to occur most commonly with basalt-rocks, melaphyres, and diabases. Trachyte has been a less frequent agent of alteration, though some remarkable examples of its influence have been noted. Poulett Scrope (*Geol. Trans.* 2nd ser. ii.) describes the alteration of a trachyte conglomerate by trachyte into a vitreous mass. Quartz-porphyry and diorite occasionally present examples of calcination, or more or less complete fusion. But with the granitic and syenitic rocks changes of this kind have never been observed. Naumann, 'Geognosie,' i. p. 744.

[3] *N. Jahrb.* 1872, p. 7. For other examples see Mohl, *Verhandl. Geol. Reichsanst.* 171, p. 259; Hussak, *Tschermak's Min. Mittheil.* 1883, p. 530.

[4] Usually the vitreous band at the margin of a basalt dyke belongs to the intruded rock and not to that through which it has risen (*ante*, pp. 235, 735, 745).

sion of the coal into a hard and brittle kind of anthracite or "blind coal," owing to the loss of its more volatile portions (west of Fife). This change may be observed in a coal-seam 6 or 8 feet thick, even at a distance of 50 yards from a large dyke. Traced nearer to the eruptive mass, the coal passes into a kind of pyritous cinder, scarcely half the original thickness of the seam. At the actual contact with the dyke, it becomes by degrees a kind of caked soot, not more perhaps than a few inches thick (South Staffordshire, Ayrshire). Coal has sometimes even been turned into graphite (New Cumnock, Ayrshire).[1]

The basalt of Meissner (Lower Hesse) overlies a thick stratum of brown coal which shows an interesting series of alterations. Immediately under the igneous rock, a thin seam of impure earthy coal ("letten") appears as if completely burnt. The next underlying stratum has been altered into metallic-lustred anthracite, passing downwards into various black glossy coals, beneath which the brown coal is worthless. The depth to which the alteration extends is 5·3 metres.[2] Another example of alteration has been described by G. vom Rath from Fünfkirchen in Hungary.[3] A coal-seam has there been invaded by a basic igneous rock (perhaps diabase) now so decomposed that its true lithological character cannot be satisfactorily determined (see p. 775). Here and there, the intrusive rock lies concordantly with the stratification of the coal, in other places it sends out fingers, ramifies, abruptly ends off, or occurs in detached nodular fragments in the coal. The latter, in contact with the intrusive material, is converted into prismatic coke. The analysis of three specimens of the coal throws light on the nature of the change. One of these (A) shows the ordinary composition of the coal at a distance from the influence of the intrusive rock; the second (B), taken from a distance of about 0·3 metre (nearly 1 foot), exhibits a partial conversion into coke; while in the third (C), taken from immediate contact with the eruptive mass, nearly all the volatile hydrocarbons have been expelled.

	Ash.	Sulphur.	Coke.	Bitumen.
A.	8·29 per cent.	2·074	79·7	20·3
B.	9·73 ,,	1·112	87·8	12·2
C.	45·96 ,,	0·151	95·3	4·7

During the subterranean distillation arising from the destruction or alteration of coal and bituminous shales, while the gases evolved find their way to the surface, the liquid products, on the other hand, are apt to collect in fissures and cavities. In Central Scotland, where the coal-fields have been so abundantly pierced by igneous masses, petroleum and asphaltum are of frequent occurrence, sometimes in chinks and veins of sandstones and other sedimentary strata, sometimes in the cavities of the igneous rocks themselves. In West Lothian, intrusive sheets, traversing a group of strata containing seams of coal and oil-shale, have a distinctly bituminous odour when freshly broken, and little globules of petroleum may be detected in their cavities. In the same district, the joints and fissures of a massive sandstone are filled with solid brown asphalt, which the quarrymen manufacture into candles.

[1] For a recent account of this Cumnock example see H. Bolton, *Trans. Geol. Soc. Manchester*, xxiii. (1895). The coal has been made columnar and the columns at their junction with the basalt pass into graphite, which adheres to the intrusive rock.

[2] Moesta, 'Geologische Schilderung, Meissner und Hirschberge,' Marburg, 1867.

[3] G. vom Rath, *N. Jahrb.* 1880, p. 276. In the above analyses the bitumen includes all volatile constituents driven off by heat, hence coke and bitumen = 100. Another instance is described by Gümbel from Mahrisch-Ostrau, where coal is coked by an augite-porphyry, *Verh. Geol. Reichsanst.* 1874, p. 55.

Propylitisation.—Reference may be made here to the changes superinduced in rocks by the influence of hot vapours and gases (solfataric action, p. 313). Among these alterations, whereby the characters of the original propylites of Western America have been induced, are the conversion of hornblende and biotite into green chloritic pseudomorphs, and that of the felspars into epidote.

Marmarosis.—The most frequent alteration undergone by limestone when invaded by an eruptive rock is its conversion into crystalline or saccharoid marble. This change may extend only an inch or two from the edge of a dyke, but may stretch over hundreds of yards where the eruptive mass has been of large size. As a rule it is more pronounced in connection with acid than with basic igneous rocks. A pure limestone will give rise only to crystalline calcite grains, but if, as so frequently happens, admixtures of non-calcareous sediment are present, they induce the development of other minerals, such as tremolite and garnet.

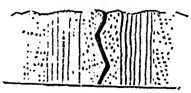

Fig. 341—Dykes of basalt (*a a a*) traversing chalk (*b b*), which near the dykes is converted into marble (*c c*), Rathlin Island, Antrim.

One of the earliest described examples of this change is that at Rathlin Island, off the north coast of Ireland (Fig. 341). Two basalt dykes (20 and 35 feet thick respectively) ascend there through chalk, of which a band 20 feet thick separates them. Down the middle of this central chalk band runs a tortuous dyke one foot thick. The chalk between the dykes and for some distance on either side has been altered into a finely granular marble.[1] On the east side of the great intrusive mass of Fair Head the chalk is likewise marmarised. Another smaller but interesting illustration of the same change occurs at Camps Quarry near Edinburgh. The dull grey Burdie House limestone (Lower Carboniferous), full of valves of *Leperditia* and plants, has there been invaded by a basaltic dyke, which, sending slender veins into the limestone, has enclosed portions of it. The limestone is found to have acquired the granular crystalline character of marble, each little granule of calcite having its own orientation of cleavage planes (Fig. 342).

Fig. 342.—Section of limestone (*a*) (Burdie House) converted into granular marble by basalt (*b*). Magnified 20 diameters.

Production of New Minerals.—Among the phenomena of metamorphism, whether contact or regional, none is more conspicuous than the development of new minerals in the rocks affected. Where the alteration has resulted in fusion, microlites or more definite crystals are found in the glasses, such minerals as pyroxene, hypersthene, cordierite, spinel, biotite, ilmenite, &c., being discernible with the microscope. Where, on the other hand, the metamorphism has spread further and may have

[1] Conybeare, *Trans. Geol. Soc.* iii. p. 210 and Plate x. One of the most remarkable examples of marmarosis is the alteration of the (Triassic) limestone of Carrara into the well-known statuary marble (see *postea*, p. 804).

been due not merely to the high temperature of the eruptive mass but to the vapours with which it was impregnated, a much more conspicuous development of new minerals is observable. These minerals have usually an obvious genetic relation to the composition of the rocks in which they are formed, but in many cases they also bear witness to the introduction of elements which were not originally present in these rocks. In argillaceous strata, such as clay-slates, as Mr. Hutchings has pointed out, one of the most unfailing and sensitive indications of commencing metamorphism is the progressive decrease in number and increase in size of the little rutile needles (*ante*, p. 171). Next in degree of sensibility is probably the development of minute scales of biotite. Quartz and felspar have often crystallized together and in their appearance are intimately connected. More advanced stages of alteration are marked by the presence of what have been called pre-eminently "contact-minerals," particularly cordierite, andalusite, kyanite and sillimanite. Hence a certain general order of succession in the development of the minerals may be traced across a broad areola of contact-metamorphism. On the outer margin of the ring, the internal re-arrangements and mineralogical re-combinations show themselves in many argillaceous rocks by the appearance of small knots or concretions which are replaced further inward by recognisable silicates, such as staurolite, then by kyanite, followed perhaps further in by sillimanite, while towards the centre the dark mica which appears even in the outer parts of the ring attains a marked prominence, often accompanied with garnets and other new minerals.[1] A few examples may be cited here, but the subject will be more fully illustrated further on in connection with the production of foliation.

A simple but interesting instance of this kind of contact-metamorphism was described many years ago by Henslow, from near Plas Newydd, Anglesea. A basalt dyke, 154 feet in breadth, there traverses strata of shale and argillaceous limestone, which are altered to a distance of 35 feet from the intrusive rock, the limestone becoming granular and crystalline, and the shale being hardened, here and there porcellanized, while its shells (*Producti*, &c.), though nearly obliterated, are still traceable by their impressions. In the altered fossiliferous shale numerous crystals of analcime and garnet have been developed, the latter yielding as much as 20 per cent of lime.[2] Similar phenomena were observed by Sedgwick along the edges of intruded Whin Sill (p. 733) among the Carboniferous Limestones and shales of High Teesdale.[3] More recently the interesting contact-phenomena of this region have been studied in detail by Mr. W. M. Hutchings, who has found that below the sheet of igneous rock, which is 100 feet thick, metamorphism is distinctly appreciable through the limestones and shales down to the basement conglomerate, a vertical distance of more than 80 feet. The purer limestone has been converted into marble, quite like what might be due to the influence of granite. Argillaceous limestone has likewise been rendered completely crystalline, and amidst its re-crystallized calcite other minerals have been developed, especially idocrase, garnet and augite, the last two here and there growing out from the edge of the sill like the teeth of a saw. There occur also pale hornblende in slender needles, epidote, sphene and a good deal of re-crystallized quartz. The intercalated sandstones have been

[1] G. Barrow, *Q. J. G. S.* xlix. p. 330. For a proposed nomenclature of those rocks in successive zones of contact-metamorphism, see W. Salomon, *Congrès Géol. Internat.* Paris, 1900.

[2] *Cambridge Phil. Trans.* i. p. 402.

[3] *Op. cit.* ii. p. 175.

changed into quartzite. The shales are marked by the production of new mica, with chlorite, quartz and sometimes felspar, as well as biotite, andalusite, anthopyllite, &c. The calcareous shales display the most extreme alteration in the whole section of strata; they have sometimes been converted into a brown compact hornfels-like rock, full of garnets, and containing also idocrase, spinel (enclosed in the garnet and idocrase), the general ground mass forming a calcareous adinole. The limestone even at a distance of 60 feet from the contact has been completely re-crystallized, while small augite crystals have been developed at a distance of 40 feet.[1]

At Rongstock on the Elbe in Bohemia certain Senonian marls have been invaded by a mass of dolerite or gabbro, probably of Tertiary age. At a distance of 800 metres from the contact the strata begin to get harder in texture and darker in colour; at 500 metres their foraminifera become hardly discernible, and at 400 metres are no longer traceable, their places being taken by calcite. At 200 metres the marls regain their lighter colour and begin to show little nests of epidote. This mineral gradually attains a greater development as the intrusive mass is approached, forming groups of parallel needles until immediately at the contact the marl is found to have been converted into a greyish-white banded rock, formed of folia of epidote, garnet, and quartz, while the interstratified layers of sandstone have been indurated to the compactness of quartzite.[2]

Among localities where the development of new minerals in proximity to eruptive rock has taken place on the most extensive scale, none have been more frequently or carefully described than some in the group of mountains lying to the east and south-east of Botzen, in the Tyrol (Monzoni, Predazzo). Limestones of Lower Triassic (or Permian) age have there been invaded by masses of monzonite, granite, melaphyre, diabase, and orthoclase-porphyry. They have become coarsely-crystalline marble, portions of them being completely enveloped in the eruptive rock. But their most remarkable feature is that in them, and in the eruptive rock in contact with them, many minerals, often beautifully crystallized, have been developed, including garnet, idocrase, gehlenite, fassaïte, pistacite, spinel, anorthite, mica, magnetic iron, hæmatite, apatite, and serpentine. Some of these minerals occur chiefly or only in the eruptive masses, others more frequently in the limestone, which is marked by a lime-silicate hornstone zone along the junction. But these are all products of contact of the two kinds of rock. Layers of carbonates (calcite, also with brucite) alternate with laminæ and streaks of various silicates, in a manner strikingly similar to the arrangement found in limestones among areas of regional metamorphism, where no visible intrusive rock has influenced the phenomena.[3]

Alteration of the Intrusive Rock.—While the igneous masses have produced more or less metamorphism in the rocks with which they have come into contact, they have not infrequently themselves undergone considerable simultaneous modifications both of composition and structure. Perhaps the most conspicuous illustrations of this reaction are supplied where basic intrusions have forced their way among highly carbonaceous

[1] W. M. Hutchings, *Geol. Mag.* 1898, pp. 69, 123.

[2] Professor Hibsch, *Verhandl. K. K. Geol. Reichsanst.* Vienna, 1889, No. 11, p. 204; Bäckström, *Geol. Fören. Stockholm*, xiii. (1891), p. 578.

[3] On the Monzoni region, see Doelter, *Jahrb. Geol. Reichsanstalt*, 1875, p. 207, where a bibliography of the locality up to the date of publication will be found. Other papers have since appeared, of which the following dealing with the phenomena of contact-metamorphism may be mentioned. G. vom Rath, *Z. D. G. G.* 1875, p. 343; 'Der Monzoni in südostlichen Tirol,' Bonn, 1875; Lemberg, *Z. D. G. G.* 1877, p. 457. O. v. Hüber, *Z. D. G. G.* li. (1899), p. 89; and the memoir of Brögger on the succession of the eruptive rocks of Predazzo, being Part ii. of his work on the eruptive rocks of the Christiania district, cited *ante*, p. 217.

strata. A compact crystalline black heavy basalt or diabase, when it sends sheets and veins into a coal or bituminous shale, becomes yellow or white, earthy, and friable, loses weight, ceases to have any apparent crystalline texture, and, in short, passes into what would at first unhesitatingly be pronounced to be mere clay. It is only when the distinctly intrusive character of this substance is recognised in the veins and fingers which it sends out, and in its own irregular course in the altered coal, that its true nature is made evident. Microscopical examination shows that this "white-rock" or "white-trap" is merely an altered form of some diabasic or basaltic rock, wherein the felspar crystals, though much decayed, can yet be traced, the augite, olivine, and magnetite being more or less completely changed into a mere pulverulent earthy substance. Traces of the glassy selvage of contact may still sometimes be detected in these altered rocks.

Examples of this alteration of the intrusive rock have been above referred to. They may be frequently observed in Central Scotland, where the coal-seams in the coal-fields have been destroyed by injected sheets of basalt, and where, along the shores of the Firth of Forth, as well as in water-courses and quarries, innumerable instances occur of the invasion of black shales by similar material with the consequent production of "white-trap." The following chemical analyses show that basic rocks which have undergone this kind of alteration have been converted into kaolin and carbonates.

	I.	II.
Silica	38·830	36·8
Alumina	13·250	22·95
Lime	3·925	9·73
Magnesia	4·180	2·85
Soda	0·971	0·5
Potash	0·422	1·1
Iron protox. . . .	13·830	4·08
Iron perox. . . .	4·335	2·6 TiO_2
Carbonic acid . . .	9·320	11·9
Phosphoric acid . . .	...	0·75
Mangan. protox. . .	...	trace
Water	11·010	7·7
	100·073	100·96

I. From the South Staffordshire coal-field. Analysed by Henry, *Mem. Geol. Surv.*, "South Staffordshire," p. 118. An account of "white-trap" by Jukes is given in this memoir.

II. From Newhalls, South Queensferry, Linlithgowshire. Analysed by E. Stecher, *Tschermak's Mittheil.* i. (1887), p. 190; *Proc. Roy. Soc. Edin.* 1888. These papers contain the result of Dr. Stecher's investigation of a collection of specimens which I sent to him in illustration of the phenomena of contact-metamorphism in the basin of the Firth of Forth.

In studying the microscopic structure of the rocks which have been altered in this way, Dr. Stecher has shown that along the edges of contact with the sandstones or shales, the diabases present a great abundance of well-defined crystals of olivine, that as the rock is examined progressively further from the contact, these crystals become more or less corroded, while in the centre of the sheet they so entirely disappear that the rock appears as a diabase without olivine. He found that the interior parts of the mass are more acid than the exterior parts, and he attributed this difference to the

incorporation of silica from rocks (sandstones, &c.) broken through by the diabase. The outer olivine-bearing selvage he regarded as representing the original composition of the rock at the time of its extrusion, and he thought that the assimilation of acid material by the central still fluid and slowly cooling portion led to the corrosion and re-solution of the olivine which at the time of extrusion, as proved by the marginal selvage, was already perfectly crystallized out. In some of the rocks he found a surplus of silica which had crystallized as quartz. Recognising that the first portion to take definite crystalline form would be more basic than the still liquid portions, he yet concluded that this will not account for the observed facts, which in his opinion point to an actual addition of silica.[1]

Basic rocks have exerted a caustic influence more especially upon the fragments (xenoliths) of other rocks which they have caught up and involved. By this action they have incorporated some foreign material into their substance so as to modify their chemical constitution and to leave unused only a few refractory minerals like zircon, sapphire, and others. It has been supposed that no such action occurs among acid rocks.[2] It is true that in what may be regarded as plutonic or deep-seated masses of these rocks caustic absorption of this kind appears to be absent. But instances have been multiplying in late years of large intrusive masses of acid material which, probably connected with volcanic protrusions, and therefore exercising their influence nearer the surface and under diminished pressure, have unquestionably dissolved more or less of the rocks through which they have risen. Their caustic action has been most marked when brought to bear upon materials comparatively basic in composition, as where granophyre has penetrated and incorporated gabbro.

The instructive example of this action described in 1894 by Professor Sollas from Barnavave near Carlingford, in the north-east of Ireland, showed that a Tertiary gabbro already solid and traversed by joints and cracks was invaded by granitic (or granophyric) material, which must have been in a state of great fluidity so as to be injected into the minutest crevices of the older rock (compare Fig. 313). This acid material has absorbed so much of the gabbro as to present distinct differences of mineralogical and chemical composition, according to the amount and constitution of the portions thus assimilated. Professor Sollas believes that at least four varieties of the acid rock owe their characters to this cause—biotite-granophyre, biotite-amphibole-granophyre, augite-granophyre, and diallage-amphibole-augite-granophyre.[3]

Another instance is supplied by the granophyre of Carrock Fell, already noticed (p. 710). Mr. Harker has shown that the augite has been wholly dissolved out of the portion of the gabbro at the junction and incorporated in the acid rock, and that the felspar has also in great part been dissolved, though some of the large crystals of plagioclase in the modified granophyre may belong to the gabbro, while the iron-ores and apatite remain with little or no change.[4]

A third illustration has been brought to light by Mr. Harker from the Tertiary volcanic series of Skye, where a granophyre has invaded a gabbro and has absorbed so much of the basic material as to constitute fully one-fourth of its own bulk.[5]

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[1] See his papers, cited above.

[2] Zirkel remarks, for instance, that it is not met with among the fragments enclosed in granites and syenites, "Lehrbuch der Petrographie," i. (1893), p. 593.

[3] *Trans. Roy. Irish Acad.* xxx. Part xii. (1894), p. 477.

[4] *Q. J. G. S.* li. (1895), p. 136.

[5] *Op. cit.* lii. (1896), p. 320.

Production of Foliation.—The most extreme form of contact-metamorphism has been reserved for the last part of this section. In this case not only have new minerals been developed, but the whole texture, structure, and composition of the altered rock have been changed, and this transformation has sometimes been accompanied by such a complete transfusion or interblending of the erupted and the metamorphosed rock that no sharp line can be drawn to define their respective limits. Reference has already been made to some of the aspects of this commingling in connection with the relation of certain intrusive masses of granite. We have now to consider it rather as it has affected the rocks into which the granite has been intruded. The chief feature of this intensest type of contact-metamorphism is the production of a foliated structure, which in different cases may be observed in every stage of development, from the incipient micaceous films of a clay-slate or phyllite up to the thoroughly crystalline condition of a schist or gneiss. This structure is recognisable whether the line of separation between the eruptive rock and its surroundings is distinct, or is lost in that *lit par lit* alternation which has already been described (p. 728). In its feebler development it can be seen to have followed the pre-existing divisional planes of the rocks affected by it. In some cases these planes have been those of bedding, in others they have been those of cleavage, when the latter had become the most pronounced. But in the extreme stages it is sometimes difficult or impossible to decide whether the planes of foliation represent previously existing planes or have been developed along a new series connected with the influence of the intrusive rock. Where a group of sedimentary rocks of tolerably various petrographical characters strikes at a large eruptive boss, so as to present to it the ends of successively different strata, the foliation which follows approximately the margin of the igneous mass, and crosses the strike of the stratification of the metamorphosed rocks, must obviously be due to the action of the invading material. The petrographical contrasts between the original sediments will still be evident in their metamorphosed condition, so that the character of the material and the degree of its foliation may be expected to vary as the metamorphism is followed from argillaceous to siliceous or calcareous bands. These features have a special significance, as they connect in the most intimate way the phenomena of contact and regional metamorphism.

It is natural that various opinions should be entertained as to the cause of the rough parallelism which may thus be traced between the margin of the eruptive mass and the direction of the foliation in the immediately adjacent rocks. If we regard the foliation in regional metamorphism as having had its planes determined by shearing stresses, increasing even to rupture, we may suppose that some similar mechanical effects were produced around a great boss of eruptive material driven like a huge wedge into the terrestrial crust, and that along the planes of cleavage or rupture thus orginated the foliation was simultaneously or subsequently developed, with the co-operation of the mineralising agents supplied from the intrusive mass. There appear to be cases where large masses of eruptive material have taken their places in the crust before the

completion of the organic movements, and have consequently undergone some part of the stresses to which the foliation of the surrounding rocks is ascribed.[1] On the other hand, without invoking mechanical aid we may seek the explanation in a possible permeation of the metamorphosed rocks by the mineralising agents successively passing outward from the body of intruded magma, with the consequent formation of successive zones of re-crystallization parallel with the periphery of the plutonic mass. Or we may consider whether there might not be an actual transference of the magma itself across the surrounding rocks which it was able to absorb and incorporate, so as in cooling and crystallizing to give rise to segregations of minerals along successive planes parallel to the body of cool rock outside and to the surface of the hot mass inside.

A vast number of instances of such extreme forms of contact-metamorphism have now been described in detail from all parts of the world. Space can be found here for only a few illustrative examples, taken from some leading types of intrusive rock.

Granite.—Round the granite bosses of Devon and Cornwall, already referred to (*ante*, p. 728), the Devonian and Carboniferous formations have undergone remarkable changes, which have long been cited as classic examples of contact-metamorphism. Fine greywacke and slate have been converted into mica-schist and varieties of gneiss (cornubianite). In some cases the slates become indurated and dark in colour, and new minerals (schorl, chiastolite, &c.) are developed in them. The volcanic bands intercalated with the sedimentary series likewise undergo alteration, the "greenstones," in particular, becoming much more coarsely crystalline as they approach the granite. Each boss of granite is surrounded with its ring of metamorphism, which varies greatly in breadth and in the intensity of alteration.[2] Interesting sections may be seen near Victoria, Cornwall, which show the manner in which schorl has been introduced from below into the slates and has given rise to schorl-schist. It will be remembered that schorl contains some 10 per cent of boric acid and a little fluorine, two of the mineralising agents which are regarded as especially effective in the contact-metamorphism produced by granite. In the sections here referred to, the schorl has been introduced into vertical joints or fissures of the silvery slates or killas (Fig. 343, A),

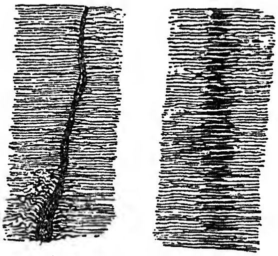

Fig. 343.—Dyke-like portions of Schorl-schist in Devonian slate, west of Victoria, Cornwall.

[1] As already pointed out (p. 718), this development of the crystalline structure in plutonic rocks at such a time and under such conditions is Dr. Weinschenk's *piezocrystallization*. *Compt. rend. congrès. Géol. Internat.* Paris, 1900, p. 340.

[2] De la Beche, 'Report on Geology of Devon and Cornwall,' *Mem. Geol. Survey*, 1839, p. 268. See also Forbes, *Trans. Geol. Soc. Cornwall*, ii. p. 260, and Boase, *op. cit.* iv. (1832), p. 166. The microscopic structure of the unaltered slates of Cornwall has been described by Allport, *Q. J. G. S.* xxxii. (1876), p. 407, and that of the greenstones by J. A. Phillips, *op. cit.* xxxiv. (1878). Some interesting observations on the metamorphism of Cornish and other slates are given by Sorby in his Address to the Geological Society, *op. cit.* xxxvi. (1880), p. 81 *et seq.* More recent information regarding the granite and metamorphism of the south-west of England has been supplied by General M'Mahon, *Q. J. G. S.* xlix. (1893), p. 385; l. (1894), p. 338; F. Rutley, *Q. J. G. S.* lii. (1896), p. 66; Busz, *Geol. Mag.* 1896, p. 492; A. Somervail, *Geol. Mag.* 1898, p. 509.

which for a distance of three or four inches on either side have been bleached from their usual pink tint into white and pale yellow. The laminæ of the slates have sometimes been puckered, and between them the schorl has been deposited in thin black leaves. Those leaves rapidly die out on either hand; and as they are piled above each other with only thin partings of slate between them, they look at a little distance like black veins or dykes, from a few inches to a foot or more in breadth (Fig. 343, B). Where they occur, the slates, which are usually soft and decomposing, have been greatly indurated; the granite is probably in place at no great depth below, but it does not here reach the surface. It has evidently given off, however, mineralising solutions which ascended through weak parts of the slates, introducing into them the silica which has indurated the rock and formed eyes of quartz and likewise the aluminous silicate, with its boric acid, fluorine, and iron-oxide, which separated out as schorl.

In the Lake District of the north of England excellent examples of the phenomena of contact may be observed round the granite of Skiddaw. The alteration here extends for a distance of two or three miles from the central mass of granite. The slate, where unaltered, is a bluish-grey cleaved rock, weathering into small flakes and pencil-like fragments. Traced towards the granite, it first shows faint spots,[1] which increase in number and size until they assume the form of chiastolite crystals, with which the slate is now abundantly crowded. The zone of this chiastolite-slate seldom exceeds a quarter of a mile in breadth. Still closer to the granite, a second stage of metamorphism is marked by the development of a general schistose character, the rock becoming more massive and less cleaved. The cleavage-planes are replaced by an incipient foliation due to the development of abundant dark little rectangular or oblong spots, probably imperfectly crystallized chiastolite, this mineral, as well as andalusite, occurring also in large crystals, together with minute flakes of mica (spotted schist, Knotenschiefer). A third and final stage is reached when, by the increase of the mica and quartz-grains, the rock passes into mica-schist—a light or bluish-grey rock, with wonderfully contorted foliation, which is develped close to the granite, there being always a sharp line of demarcation between the mica-schist and the granite.[2]

In the same region the granite boss of Shap has produced some interesting changes on the andesitic rhyolitic and more basic lavas and tuffs associated with the Lower Silurian strata. These changes have been studied by Messrs. Harker and Marr, who describe the gradual alteration of the andesites by the development of brown mica, hornblende, sphene, and other minerals. The amygdaloidal cavities had been filled with secondary products, and the rocks had been considerably weathered before the intrusion of the granite, for the materials filling the vesicles partake in the general metamorphism. By the gradual increase of the brown mica and the production of a marked laminated structure indicated by the parallel disposition of the mica-flakes, these lavas and tuffs assume the aspect of true crystalline schists.[3]

Farther north, in the south-western counties of Scotland, several large masses of fine-grained granite rise through the Lower Silurian greywacke and shale, which, around the granite for a variable distance of a few hundred yards to nearly two miles, have undergone great alteration (see Fig. 300). These strata are ranged in steep anticlinal and synclinal or isoclinal folds, which run across the country in a general

[1] Mr. Hutchings has found that in the neighbouring district of Shap the spots which were thought to be probably andalusite consist of cordierite, and in some cases of white mica. *Geol. Mag.* 1894, p. 65.

[2] J. C. Ward, *Q. J. G. S.* xxxii. (1876), p. 1. Compare the development of andalusite in regional metamorphism, p. 797, note.

[3] Harker and Marr, *Q. J. G. S.* xlvii. (1891), p. 266, and xlix. (1893), p. 359, where some interesting conclusions are given as to the trivial and partial nature of the chemical changes produced by thermometamorphism.

north-east and south-west direction. It is observable that this normal strike continues, with little modification, up to the granite, which thus has replaced an equivalent area of sedimentary rock (see p. 728). The coarser arenaceous beds, as they approach the granite, are changed into quartz-rock, the thin siliceous shales into Lydian-stone, the black anthracitic graptolite-shales into a compact mass charged with pyrites, and breaking into large rough blocks. The radiolarian cherts pass from their usual flinty texture into coarsely crystalline quartz-rocks. Strata wherein felspar-grains abound have been altered to a greater distance than the more siliceous beds, and show a gradation through spotted schists, with an increasing development of mica and foliation, until along the edge of the granite they become true mica-schist and even a fine kind of gneiss.[1] The pebbly conglomerates which form a marked horizon among the unaltered rocks, are traceable in the metamorphosed areole as rocks which, at first sight, might be taken for some kind of porphyritic gneiss. Their quartz-pebbles have assumed a resinous aspect, and are enveloped in a crystalline micaceous paste.

The French Pyrenees present instructive examples of the effect of the protrusion of granite and other eruptive rocks upon Cambrian and later formations. Fuchs traced the metamorphism of clay-slate through spotted schists (frucht-, chiastolite-, and andalusite-schists) into mica-schist and gneiss.[2] The region was afterwards studied in great detail by Barrois, who distinguished three successive zones in the metamorphic areola surrounding the granite. On the outside lies the zone of "goffered schists," in which a puckered structure has been developed without any new mineral combination of the elements of the rock. Next come the chiastolite-schists, with crystals of chiastolite, tourmaline, &c., which become more and more micaceous towards the interior, till they pass into the third and innermost zone, that of the leptinolites, which are highly micaceous schists with small crystals of chiastolite, and sometimes with tourmaline, rutile, and triclinic felspar. Barrois also showed that round the masses of kersantite a ring of chloritic mica-schist has been developed, followed outside by one of spotted schists.[3]

More recently the granite of the Pyrenees and its contact phenomena have been made the subject of detailed studies by Lacroix. He shows that in the Haute Ariège the Silurian or Devonian clay-slates not only pass into the usual phyllitic and micaceous condition, but become like the most ancient mica-schists, and immediately next the granite have been felspathised until they assume even a gneissic aspect. The felspathic substance is supposed to have been introduced partly by imbibition, and is then only discoverable by the aid of the microscope, partly by injection where the granite has penetrated in thin layers between the laminæ of the schists. Great changes are likewise made on the limestones, which assume the usual marmarised forms, with numerous metamorphic minerals, passing into garnet rocks, epidote rocks, and other compounds. In discussing the origin of these changes, Lacroix adopts the view that they have been essentially brought about through the influence of the mineralising agents with which the granite was charged. He further shows that the granite itself presents great diversity of composition in different parts of its mass, passing into diorite, norite, and

[1] J. Horne, *Mem. Geol. Surv. Scotland*, Explanation of Sheet 9, p. 22. *Brit. Assoc.* 1892, p. 712. J. Horne and J. J. H. Teall, *Mem. Geol. Surv. Scotland*, Explanation of Sheet 5, and more especially the large Memoir on the Silurian Rocks of Scotland (1899), chap. xxviii. The microscopic structure of the altered rocks in this district has been studied by Professor Bonney and Mr. Allport, *Proc. Roy. Soc.* xlvi. (1889), and Miss M. J. Gardiner, *Q. J. G. S.* xlvi. (1890), p. 569.

[2] *N. Jahrb.* 1870, p. 742; see also Zirkel, *Zeitsch. Deutsch. Geol. Ges.* xix. (1867), p. 175.

[3] 'Recherches sur les Terrains anciens des Asturies et de la Galice,' quarto, Lille, 1882; J. Roussel, *Bull. Carte. Géol. France*, v. No. 35 (1893); Carez, *B. S. G. F.* xxiv. (1896), p. 389; xxv. (1897), p. 456; Caralp, xxiv. p. 528; Stuart Menteith, p. 898.

even peridotite, and he accounts for these differences not by supposing any differentiation of the constituent materials of the rock, but by supposing that the granite has probably involved and assimilated in various proportions the calcareous sediments through which it has risen.[1]

A large series of important observations has been made by Barrois in Brittany with regard to the granites and metamorphism of that region. Thus at Guémené, in the maritime department of Morbihan, where Lower Silurian strata have been invaded by granite, the sandstones (grès à scolithes) have been converted into micaceous quartzites. These altered rocks, traced farther inwards, are further distinguished by the development in them of sillimanite, sometimes in sufficient abundance to impart a foliated, undulated, gneissoid structure. At the contact with the eruptive rock, this quartzite shows re-crystallized quartz, black mica, sillimanite, cordierite, and a good many crystals of orthoclase and plagioclase, besides white mica. The matrix of the conglomerates is altered into a mass composed of rounded or angular grains of quartz united by abundant white sericitic mica, and containing some crystals of zircon, large plates of muscovite, and yellow granules of limonite.[2]

In connection with the French examples of contact-metamorphism reference may again be made here to the important researches of M. Michel-Lévy on the extent to which sedimentary rocks have been transformed into crystalline schists by the introduction of granitic material into them (*ante*, p. 728). It has been proved by this geologist, and his observations have since been confirmed in other countries, that in some cases (which are probably more frequent than has been suspected) the strata have been "granitised" or permeated with the constituents of granite not merely as large veins or dykes, but in minute threads and laminæ, which follow generally the more marked divisional planes, such as those of bedding, cleavage, or foliation. To quote only one example in this place, near the contact of the micaceous schists of Saint Léon with the granite which pierces them, this observer found that the eruptive rock has been injected between the planes of the schists in leaves from a few millimetres to one or two centimetres thick. The rock has thus a ribboned appearance from the alternation of numerous dark micaceous layers with the finely granular pink or white seams of granite. By such a process of metamorphism and injection, undoubted sedimentary strata have acquired a structure that can hardly be distinguished from that of some ancient gneisses.[3]

Another admirable locality for the study of contact-metamorphism is the eastern Vosges. Rosenbusch, in describing the phenomena there, has shown that the unaltered clay-slates are grey, brown, violet, or black, thinly fissile, here and there curved, crumpled, and crowded with kernels and strings of quartz.[4] Traced towards the granite of Barr Andlau, they present an increasingly pronounced metamorphism. First they assume a spotted appearance, owing to the development of small dark points and knots, which increase in size and number towards the granite, while the ground-mass remains unaltered (knotenschiefer, fruchtschiefer). The ground-mass of the slate then becomes lighter in colour, harder, and more crystalline in appearance, while flakes of mica and quartz-grains make their appearance. The knots, now broken up, rather increase than

[1] *Bull. Carte. Géol. France*, No. 64, tome x. 1898; No. 71, tome. xi. 1900. (See *ante*, p. 710.)

[2] *Ann. Soc. Géol. Nord.* xl. (1884), p. 103; xii. pp. 1, 68; xv. p. 238; xvi. p. 10; *Bull. Carte Géol. France*, No. 7, 1889. The occurrence of trilobites and orthids in slates so altered as to contain well-developed crystals of chiastolite was long ago noticed by Puillon-Boblaye (*Compt. rend.* vi. 1836, p. 168); his observations were confirmed by the Comte de Limur, *B. S. G. F.* xiii. p. 55.

[3] See besides the papers by Michel-Lévy, Horne, and Greenly, cited *ante*, p. 729, another by the first-named author, *Congr. Géol. Internat.* 1888, p. 59.

[4] *Neues Jahrb.*, 1875, p. 849, 'Die Steigerschiefer und ihre Contact-Zone,' Strassburg, 1877. Unger, *Neues Jahrb.*, 1876, p. 785.

diminish in size; the hardness of the rock rapidly increases, and the fissile structure becomes unrecognisable on a fresh fracture, though observable on a weathered surface. Still nearer the granite, the knot-like concretions disappear from the rock, which then has become an entirely crystalline mass, in which, with the lens, small flakes of mica and grains of quartz can be seen, and which under the microscope appears as a thoroughly crystalline aggregate of andalusite, quartz, and mica. The proportions of the ingredients vary, but the andalusite and quartz usually greatly preponderate (andalusite-schist). Chemical analysis shows that the unaltered clay-slate and the crystalline andalusite-schist next the granite consist essentially of similar chemical materials, and that "probably the metamorphism has not taken place by the addition or subtraction of matter, but by another and still unknown process of molecular transposition."[1] In some cases, boric acid has been supplied to the schists at the contact.[2] Still more striking, perhaps, is the condition of the rocks at Rothau; they have become hornblendic, and their included corals have been replaced, without being distorted, by crystals of hornblende, garnet, and axinite.[3]

In the Christiania district of Southern Norway, singularly clear illustrations of the metamorphism of sedimentary rocks round eruptive granite have long been known. Kjerulf has shown that each lithological zone of the Silurian formations, as it approaches the granite of that district, assumes its own distinctive kind of metamorphism. The limestones become marble, with crystals of tremolite and idocrase. The calcareous and marly shales are changed into hard, almost jaspery, shales or slates; the cement-stone nodules in the shales appear as masses of garnet; the sandy strata become hard siliceous-schists (hälleflinta, jasper, hornstone) or quartzite; the non-calcareous black clay-slates are converted into chiastolite-schists, or graphitic schists, but often show to the eye only trifling alteration. Other shaly beds have assumed a fine glimmering appearance; and, in the calcareous sandstone, biotite has been developed. In spite of the metamorphism, however, neither fossils nor stratification have been quite obliterated from the altered rocks. From all the stratigraphical zones fossils have been found in the altered belt, so that the true position of the metamorphosed rocks admits of no doubt.[4] Professor W. C. Brögger has subjected the rocks of the zones of contact-metamorphism round Christiania to a searching microscopic examination, and has published a highly important and interesting memoir on the subject. He describes the unaltered and altered conditions of the more conspicuous stratigraphical bands, and thus provides new material for the investigation of contact-metamorphism. Especially interesting are his descriptions of the distinctive metamorphism of each band, the remarkably variable amount of alteration even in the same band, the persistence of recognisable graptolites even in rocks that have become essentially crystalline, the transformation of limestone into marble, of which a fourth or fifth part is composed of garnet, partly in large rhombic dodecahedrons, and partly as a mould enclosing *Orthis calligramma*.[5]

Around the intrusive granite and syenite in the schist district of the Elbe valley hills in Saxony some varied manifestations of contact-metamorphism have been described by F. Becke.[6] The Silurian clay-slates have there been converted into knotted schists

[1] Unger, *op. cit.* p. 806.

[2] Rosenbusch, 'Die Steigerschiefer,' &c., p. 257.

[3] *Ann. des Mines*, 5me sér. xii. p. 318.

[4] 'Geologie Norwegens,' 1880, p. 75. For the literature of the Norwegian locality see E. Reyer, *Jahrb. Geol. Reichsanst.* xxx. (1880), p. 26.

[5] 'Die Silurischen Etagen 2 und 3 im Kristiania Gebiet,' Kristiania, 1882. Reference may be made here to the excellent monograph by H. Bäckström on the crystalline rocks of Vestanå, Scania, in Southern Sweden, *Handl. K. Svensk. Vetensk. Akad.* xxix. (1897). He there describes the metmorphism of a series of quartzites and other sedimentary rocks, including certain dacite-tuffs.

[6] *Tschermak's Mittheil.* xiii. (1893), p. 290. Round the syenite of Meissen in Saxony,

and hornfels; the Kieselschiefer into graphitic quartzite; the limestones into marble and lime-silicate rocks with impregnation of iron-ores; the diabases and diabase-tuffs (schalsteins) into hornblendic rocks. The Devonian greywacke has been, in like manner, turned into hornfels and knotted mica-schist, while the conglomerate, still retaining its recognisable quartz and quartzite pebbles, has had its ground mass entirely altered into a holocrystalline aggregate of quartz and biotite, together with muscovite and plagioclase. Some of the rocks even assume a gneissoid character.

One further European example may be cited from the observations of F. E. Müller, who has described round the granite of the Hennberg near Lehesten in the Frankenwald the occurrence of knotted schists, chiastolite-schists, knotted mica-schists, and andalusitic mica-rocks.[1]

The same phenomena have been observed in many other parts of the world. One example from America may suffice to show how precisely the facts collected in the Old World are repeated in the New. An elaborate examination was made of the contact-metamorphism of the granite of Albany, New Hampshire, by the late Mr. G. W. Hawes.[2] His analyses indicate a systematic and progressive series of changes in the schists as they approach the granite. The rocks are dehydrated, boric and silicic acids have been added to them, and there appears to have been also an infusion of alkali directly on the contact. He regarded the schists as having been impregnated by very hot vapours and solutions emanating from the granite.

Diorite.—On the whole, it may be said that the breadth and intensity of contact-metamorphism decrease in proportion to the increase of basicity in the eruptive mass. Granitic and allied acid rocks present the broadest zones of alteration, and in these the transformations reach a maximum, while around rocks like basalt the metamorphism is often comparatively slight, and seldom extends many feet beyond the immediate neighbourhood of the intrusive mass. The complicated group of diorites and other rocks described by G. H. Williams as the "Cortland" series of Peekshill, New York, have been shown by J. D. Dana and by him to be accompanied by an interesting series of alterations of the surrounding schists and limestones. As the mica-schists are followed across the strike in the direction of the intrusive mass, they are observed to become more and more puckered, the intensity of the alteration increasing in proportion as the intrusive rocks are approached, but at the actual contact the original schistose structure almost wholly disappears and the rock becomes hard and massive, sometimes consisting of an almost colourless pyroxene with some hornblende and quartz. The metamorphism, as shown by the disappearance of the quartz and muscovite of the schists and the development of biotite, sillimanite, staurolite, kyanite, and garnet, consists of an addition of alumina and iron and a corresponding decrease in the proportions of silica and the alkalies. No fewer than eighteen minerals are enumerated as having been developed by contact-metamorphism in the zone of alteration.[3]

Diabase.—A classical region for the study of contact-metamorphism is in the Harz. Besides the granite masses of the Brocken and Ramberg, around which the Devonian and older Palæozoic rocks are altered into various flinty slates and schists, dykes and other masses of a crystalline diabase have been erupted through the greywackes and shales. These strata at the contact and for a varying distance beyond, have been converted into hard siliceous bands (hornstone) and into various finely foliated masses (fleckschiefer, bandschiefer, contactschiefer, the spilosite and desmosite of Zincken).

the diabases, when they come within the areole of contact-metamorphism, pass into actinolite-schists and anthophyllite-schists. K. Dalmar, Blatt 64 (Tanneberg) *Erläuter. Special-Kart. Sachsen* (1889); A. Sauer, *op. cit.* Blatt 48 (Meissen).

[1] *Neues Jahrb.* 1882 (2), p. 205.

[2] *Amer. Journ. Sci.* xxi. (1881), p. 21.

[3] Dana, *Amer. Journ. Sci.* xxii. (1881), p. 314; G. H. Williams, *op. cit.* xxxvi. (1888), p. 254.

The limestones have their carbon dioxide replaced by silica in a broad zone of lime-silicate along the contact.[1] The black compact limestone of Haserode becomes a white saccharoid marble, charged with silicates (rhombic dodecahedrons of garnet, &c.) and with its carbonaceous matter segregated into abundant veins. A limestone band containing ironstone presents, in the Spitzenberg between Altenau and Harzburg, a garnetiferous magnetite containing well-preserved crinoid stems.[2]

Lherzolite and **Ophite.**—The limestones and calcareous shales of Liassic age in the Pyrenees have been invaded by masses of lherzolite, and have in consequence undergone contact-metamorphism, passing into hornfels (cornéenne), spotted mica-schists, and hornblendic rocks that present a great external resemblance to the altered rocks found around granite. Their characteristic minerals, scapolite, biotite, tourmaline, pyroxenes, amphiboles, and felspars (anorthite to orthose) have been developed in them by metamorphism, their own original individualised minerals having been obliterated, except microcrystalline calcite, and sometimes a little clastic quartz. Their colouring organic matter has been entirely removed from around the contact, but reappears some hundreds of metres away from it. Professor Lacroix in describing these phenomena points out that while the highly magnesian lherzolite has no alkalies, the metamorphosed sediments contain them in abundance as well as other elements, such as boron and titanium, which are likewise absent from the eruptive rock. He contends that although the altered strata have undoubtedly supplied a portion of the elements required for the development of the new minerals, a large part of these elements has certainly been brought up from below in the form of emanations or fumaroles, having a composition quite different from that of the eruptive rock. The action of these substances has been especially energetic along the contact which was their line of escape, and where the sedimentary rocks have been entirely transformed into silicates.[3]

Serpentine and **Fourchite** (a rock composed almost entirely of granular augite with a ground mass of finer granules of the same mineral). Certain sandstones and radiolarian cherts in Angel Island, San Francisco, have been invaded by these basic rocks, and have undergone a remarkable metamorphism along their contact with them. In each case they have been converted into holocrystalline amphibole-schists, in which the amphibole is the beautiful blue variety known as glaucophane. Both the sandstone and the cherts have undergone this transformation, which occurs with the same general characters along the contact with each of the intrusive rocks. From the fact that the schist produced from the alteration of the sandstone presents no essential difference from that formed out of the chert, and also that no distinctive feature can be detected between the metamorphism effected by the fourchite from that due to the serpentine, Mr. Ransome concludes that the unknown causes that have led to the development of the glaucophane and its accompanying minerals are not confined to any single rock, but must be dependent upon the common properties of at least two of them, the chert and sandstone on the one side, and the serpentine and fourchite on the other.[4] He thinks

[1] Zincken, *Karsten und v. Dechen, Archiv.* v. p. 345 ; xix. p. 583. Fuchs, *N. Jahrb.* 1862, pp. 769, 929. K. A. Lossen, *Z. D. G. G.* xix. p. 509 (on the Taunus) ; xxi. p. 291 ; xxiv. p. 701. Kayser, *op. cit.* xxii. p. 103. The memoirs of Lossen form some of the most important contributions to our knowledge of the phenomena of metamorphism.

[2] K. A. Lossen, *Z. D. G. G.* xxix. 1877, p. 206. *Erläuter. Geol. Special-Kart. Preuss.* Blatt, Harzgerode (1882).

[3] *Nouv. Archiv. Muséum*, Paris, 3e sér. vi. ; *Bull. Carte. Géol. France*, No. 42, vi. 1895.

[4] F. Leslie Ransome, "The Geology of Angel Island," *Bull. Geol. Univ. California*, i. No. 7 (1894), p. 193. That these glauconite-schists are the result of contact-metamorphism has been also affirmed by Professor A. C. Lawson in his sketch of the geology of the San Francisco peninsula (*15th Ann. Rep. U.S. Geol. Surv.*). More recently Mr. H. W. Turner has thrown doubt on the observations, but without any further explanation of them. *Journ. Geol.* vi. (1898), p. 490.

that possibly both the intrusive rocks may have come from the same original reservoir. If they were endowed with the same mineralising agents and possessed similar temperatures, we may suppose that they would exercise much the same kind and amount of metamorphic influence, and possibly the chemical composition of the sandstone (which contains 70·50 per cent of silica) may not have been markedly different from that of the chert.

§ ii. Regional Metamorphism—the Crystalline Schists.[1]

From the phenomena of metamorphism round a central boss of eruptive rock, we now pass to the consideration of cases where the metamorphism has affected wide areas without visible relation to eruptive matter. It is obvious, however, that in many regions eruptive rocks, though they do not appear at the surface, may lie at no great distance beneath it, and hence that what have been regarded as proofs of regional, may really be results of contact-metamorphism. The difficulty of discrimination is lessened in proportion to the extent of the region in which no exposure of igneous rock makes its appearance. Under any circumstances, only those examples are here admissible in evidence where there is distinct proof that what are called metamorphic rocks either pass into masses which have not been metamorphosed, or present characters which are proved to have been produced by the alteration either of stratified or of massive rocks, in other areas of too wide an extent to warrant the attribution of the alteration to the influence of any igneous rock. In the study of this difficult but profoundly interesting geological problem, it is desirable to begin with the examination of rocks in which only the slightest traces of alteration are discernible, and to follow the gradually increasing metamorphism, until we arrive at the most perfectly developed crystalline condition. It is the earliest stages which are of most importance, for it is there that the nature and proofs of the changes can best be established. As already remarked (p. 766), the igneous rocks,

[1] Out of the copious literature devoted to this subject it may be sufficient to cite here chiefly some of the earlier writings, in addition to others of later date, which will be referred to in the following pages: Delesse, *Mém. Savans Étrangers*, xvii. Paris, 1862, pp. 127-222; *Ann. des Mines*, xii. (1857); xiii. (1858); 'Etudes sur le Métamorphisme des Roches,' Paris, 1869; Durocher, "Études sur le Métamorphisme des Roches," *B. S. G. F.* (2), iii. (1846); Daubrée, *Ann. des Mines*, 5me série, xvi. p. 155; Bischof, 'Chemical Geology,' chap. xlviii.; J. Roth, "Ueber die Lehre von Metamorphismus," *Abhandlungen Akad. Berlin*, 1871, pp. 151-232; 1880; Gümbel, 'Oestbayerische Grenzgebirge,' 1868; H. Credner, *Zeitsch. Gesammt. Naturwiss.* xxxii. (1868), p. 353; *N. Jahrb.* 1870, p. 970; A. Inostranzeff, 'Studien über metamorphosirte Gesteine,' Leipzig, 1879; A. Heim, 'Untersuchungen über den Mechanismus der Gebirgsbildung,' 1878; A. Rothpletz, *Z. D. G. G.* xxxi. (1879), p. 374; H. Reusch, 'Die fossilien-führenden krystal-linischen Schiefer von Bergen,' German translation by Baldauf, 1883. *Neues Jahrb.* (Beilageband), 1887, p. 56; 'Bömmelöen og Karmöen,' 1888; *Rep. Geol. Congress, London*, 1891, p. 192: Lehmann, 'Untersuchungen über die Entstehung der altkrystallinischen Schiefer,' 1884; J. J. H. Teall, *Geol. Mag.* 1886, p. 481; G. H. Williams, *Bull. U.S. G. S.* No. 62 (1890). The papers on the Crystalline Schists by Heim, Lory, Lehmann, Michel-Lévy, Lawson, and the U.S. Geol. Survey in the report of the London Session of the International Geological Congress (published in 1891) should be consulted.

from the definiteness of their original structure and composition, offer special facilities for following the nature and extent of the changes involved in the metamorphism of a region or of a large series of rocks.

As in the case of contact-alteration, the extent and character of regional metamorphism depend in the first place upon the original constitution of the rock acted upon, and in the second place upon the energy of the metamorphic processes. Certain rocks resist alteration. Pure siliceous sandstones, for example, become quartzites, but generally advance no further, though occasionally, under intense strain, their particles are drawn out into a somewhat schistose arrangement. But where felspathic elements are present, particularly where they are the chief constituents, some form of mica almost invariably appears, while other new minerals and structures may be developed in progressively increasing abundance. These changes generally culminate in the production of some form of crystalline schist.

The most distinctive character of Schists is undoubtedly their foliation (p. 244, and Fig. 34). They have usually a more or less conspicuously crystalline structure, though occasionally this is associated with traces, or even very prominent manifestations, of original clastic ingredients. Their foliated or schistose structure varies from the massive or granitic type of the coarsest gneiss down to the extremely delicate arrangement of the finest talcose or micaceous schist. They occur sometimes in monotonous uniformity; one rock, such as gneiss or mica-schist, covering vast areas. In other places, they consist of rapid alternations of various foliated masses—gneiss, mica-schist, clay-slate, actinolite-schist, and many other species and varieties. Lenticular seams of crystalline limestone or marble and dolomite, usually with some of the minerals mentioned on p. 192, sometimes strongly graphitic, not unfrequently occur among them, especially where they contain bands of serpentine or other magnesian silicates. Thick irregular zones of magnetite, hæmatite, and aggregates of hornblendic, pyroxenic, or chrysolitic minerals likewise make their appearance along the folia of the gneisses.

Another conspicuous feature of Schists is their usual intense crumpling and plication. The thin folia of their different component minerals are intricately and minutely puckered (Figs. 35, 36). Thicker bands may be traced in violent plication along the face of exposed crags. So intense indeed have been the internal movements of these masses, that the geologist experiences great and often insurmountable difficulties in trying to make out their order of succession and their thickness, more especially as he cannot rely on the banding of the rocks as always or even generally an indication of consecutive deposition. Such evidence of disturbance, though usually strongly marked, is not everywhere equally so. Some areas have been more intensely crumpled and plicated, and where this is the case the rocks usually present their most conspicuously crystalline structure.

A further eminently characteristic feature of Schists is their common association with bosses and veins or bed-like sheets of granite, syenite, quartz-porphyry, diorite, epidiorite, gabbro, diabase, or other massive rocks. In some regions, indeed, so abundant are the granitic and

pegmatitic masses and so coarsely crystalline or granitoid are the schists, that it becomes impossible to draw satisfactory boundary-lines between the two kinds of rock, and the conviction arises that in some cases they may represent different conditions of the same original material, while in others they may be due to granitisation (pp. 728, 781).

The term "Crystalline Schists" has been generally applied to rocks possessing these characters, and more especially to those examples of them which underlie the oldest stratified formations. Some account of these ancient schists will be given in Book VI. Part I. At present we are concerned with the evidence which can be produced that crystalline schists are in some areas the result of a widespread metamorphism of rocks which were not originally schists, and which might not even be crystalline. In the investigation of the problem now to be considered it is especially desirable to study examples where a crystalline and foliated structure has been superinduced upon ordinary sedimentary strata without the visible intervention of any eruptive rock, or where a massive eruptive rock passes by degrees into a true schist; in short where the steps in the gradation between the unaltered and altered conditions can be clearly traced. In recent years so much attention has been given to these transformations that our knowledge of metamorphic processes has been greatly extended, and the problem of regional metamorphism, though by no means entirely solved, is at least much more clearly understood than it has ever been before.

There is now a general agreement among geologists that a fundamental condition for the production of extensive mineralogical alteration of rocks has been disturbance of the terrestrial crust, involving the intense compression, crushing, fracturing, and stretching of masses of rock. Compression, as we have seen, may give rise to slaty cleavage (p. 417). But it has often been accompanied or followed by further internal transformations in the rocks. Chemical reactions have been set up and new minerals have been formed. The effects of pressure and of movement under great strain in quickening chemical activity are now clearly recognised. Not only have the original minerals been driven to rearrange themselves with their long axes perpendicular to the direction of the pressure, but secondary minerals with well-marked cleavage have been developed along the same lines, and thus a distinctly foliated structure has been induced in what were originally amorphous rocks.

Still more marked are the changes that have resulted where the shearing movements have given way to actual rupture, and where the rocks have been crushed, faulted, and stretched. The extraordinary manner in which the crust of the earth has been fractured in some areas of regional metamorphism has been worked out in great detail by the Geological Survey in the north-west of Scotland.[1] We there perceive how slice after slice of solid rock has been pushed forward, one over the other, how those accumulated slices have been driven over others of similar kind, how this structure has been repeated again and again, not only on a great scale involving mountain-masses in the movement, but

[1] *Q. J. G. S.* xliv. (1888), p. 378.

even on so minute a scale that the ruptures and puckerings cannot be seen without a microscope (pp. 792, 886).

Such dynamical movements could not but be accompanied with wide-spread and very marked chemical rearrangements. Along the margins of faults or planes of movement where shearing has been succeeded by rupture, the rocks have been ground against each other; the crushed material has assumed a foliated structure, in which the folia are parallel to the planes of movement. This foliated selvage, with its new mineral combinations, gradually passes into the amorphous or less crushed rock on either side. In such places, sericite, biotite, chlorite, or some other secondary product with its cleavage-planes ranged in one common direction, shows the line of movement and the reality of the chemical recombinations. In the body of a mass of rock, also, subject to great strain, relief has been obtained by rupture and crushing along certain planes, with a consequent greater development of the secondary minerals along these planes, and the production of a banded or schistose structure in a rock that may have been originally quite homogeneous[1] (Figs. 266 and 367).

The recognition of the powerful part taken by mechanical deformation in producing the characteristic structures of many schistose rocks has not unnaturally led to some exaggeration on the part of geologists, who were thus provided with what appeared to be a solution of difficulties which at one time seemed insuperable. There can hardly be any doubt that the theory of mechanical deformation has been too freely used and has been applied to structures to which it cannot properly be assigned. Among the coarser gneisses, for example, the segregation of widely distinct minerals, such as quartz, felspar, hornblende, pyroxene, magnetite, &c., in more or less parallel lenticular bands is a structure that seems to find its nearest analogy in the banding of eruptive masses of gabbro and other rocks already described (p. 711), where the alternations of different material are obviously original and have arisen from the simultaneous intrusion of heterogeneous materials. The effect of subsequent mechanical deformation and crystalline rearrangement may sometimes have partially or wholly obliterated this first banding by a later foliation (Figs. 362, 368).

But while this tendency to a too liberal use of dynamical causes in explication of all the structures of the crystalline schists must be admitted, we are now furnished with ample evidence of the efficacy of mechanical movements in the production of regional metamorphism. As has been above (p. 681) pointed out, it is frequently possible to detect portions of the original structures, to show that they belonged to certain familiar and definite types of sedimentary or eruptive rocks, and to trace every stage of transition from them into the most perfectly developed crystalline schist. In the crushing down of large masses of rock during powerful terrestrial movements, lenticular cores of the rocks have frequently escaped entire destruction. Round these cores the pulverised material of the rest of the rock has been made to flow, somewhat like the flow-structure round the porphyritic crystals of a cooling lava (compare Figs. 18 and 265). Successive gradations may be followed until the cores, becoming smaller

[1] G. H. Williams, *B. U.S. G. S.* No. 62 (1890), pp. 202-207.

by degrees, pass finally into the general reconstructed material. That this structure is not original, but has been superinduced upon the rocks after their solidification, can thus be abundantly demonstrated. Among the sedimentary formations the elongation and flattening of the pebbles in conglomerates, and the transition from grits or greywackes into foliated masses, prove the structure to have been superinduced (Figs. 265, 267). Among eruptive rocks the crushing down of the original minerals, and their transformation into others characteristic of foliated rocks, afford similar proof.

So great has been the pressure exerted by gigantic earth-movements upon the rocks of the crust that even the most solid and massive materials have been sheared, and their component minerals have been made to move upon each other, giving a flow-structure like that artificially produced in metals and other solid bodies (pp. 419, 681). But it may be doubted whether this motion is ever strictly molecular without rupture of the constituent minerals. Microscopic examination shows that, at least as a general rule, the minerals in the most thoroughly bent and crushed rocks have been broken down. It is observable that under the effects of mechanical strain the minerals first undergo lamellation, twinning being developed along certain planes. This structure increases in distinctness with the intensity of the strain so long as the mineral (such as felspar) retains its cohesion, but its limit of endurance is eventually reached, beyond which it will crack and separate into fragments, which, if the movement is arrested at this stage, may be cemented together by some secondary crystallization of the same or another mineral filling up the interspaces. But should the pressure increase, the mineral may be so wholly pulverised as to assume a finely granular (mylonitic) structure or a mosaic of interlocking grains, which under the influence of continual shearing may develop a streaky arrangement, as in flow-structure and foliation.[1]

One of the most important effects of this mechanical deformation and trituration has been the great stimulus thereby given to chemical reactions. These were effected under gigantic pressures, at more or less elevated temperatures and in the presence of at least such water as may have been interstitially contained in the rocks. So constant and so great have they been, and so completely in many cases have the ingredients of the rocks been recrystallized in fresh combinations, that the new structures thus produced have been apt to mask the proof of the mechanical deformations that preceded or accompanied them. It is in the main to the light thrown on the subject by the microscopical investigation of the minute structures of the metamorphosed masses that we are indebted for the recognition of the important part played by pressure and stretching in the production of the more essential and characteristic features of metamorphic rocks. Many chemical rearrangements may undoubtedly take place apart from any such dynamical stresses, but none of these stresses appear to have affected the metamorphic rocks without being accompanied by chemical and mineralogical readjustments.

[1] Lehmann, *op. cit.* pp. 245, 249 ; G. H. Williams, *B. U.S. G. S.* No. 62, p. 47.

The mineral transformations observable in regional metamorphism "may consist (1) in the breaking up of one molecule into two or more with but little replacement of substance, as in the formation of saussurite from labradorite; (2) in a reaction between two contiguous minerals, each supplying a part of the substance necessary to form a new compound of intermediate composition, more stable for the then existing conditions than either, as in the formation of a hornblende zone between crystals of olivine or hypersthene and plagioclase; or (3) in more complicated and less easily understood chemical reactions, like the formation of garnet or mica from materials which have been brought together from a distance, and under circumstances of which it is at present impossible to state anything with certainty."[1] The following transformations especially deserve attention.

Micasisation—the production of mica as a secondary mineral from felspars or other original constituents. One of the most common forms of this change is where the silky unctuous *sericite* has been developed from orthoclase (sericitization). The formation of mica is one of the most common results of the mechanical deformation of rocks, and is most conspicuous where the pressure or stretching has been most intense. Massive orthoclase rocks, such as granite, quartz-porphyry or felsite, when most severely crushed, pass into sericite schist; felspathic grits and slates may be similarly changed.[2]

Uralitisation—the conversion of pyroxene into compact or fibrous hornblende. This change may not be a mere case of paramorphism or molecular rearrangement, but seems generally to involve a certain amount of chemical transformation, such as the surrender of part of the lime of the pyroxene towards the formation of such combinations as epidote,[3] and the higher oxidation of the iron.[4] It has taken place on the most extensive scale among the crystalline schists. Rocks which can be shown to have been originally eruptive, such as diabases, have been converted into epidiorite, and where the deformation has advanced further, into hornblende-schist or actinolite-schist.

Epidotisation—the production of epidote in a rock from reactions between two or more minerals, especially between pyroxene or hornblende and plagioclase. In some cases diabases have been converted into aggregates of epidote and quartz or calcite, epidosite, epidote-schist (p. 253).[5]

Saussuritisation—the alteration of plagioclase into an aggregate of needles, prisms, or grains (chiefly zoisite), imbedded in a glass-like matrix (albite), by an exchange of silica and alkali for lime, iron, and water. This change has largely affected the felspar of coarse gabbros or euphotides, in districts of regional metamorphism.[6]

Albitisation—a process in which, while the lime of the plagioclase is removed or crystallizes as calcite, instead of forming a lime-silicate like epidote or zoisite, the rest of the original mineral recrystallizes as a finely granular aggregate or mosaic of clear

[1] G. H. Williams, *Bull. U.S. G. S.* No. 62 (1890), p. 50. This admirable essay, with its copious bibliography, will well repay the careful perusal of the student. I am indebted to it for the abstract of metamorphic processes above given. The student may usefully consult the suggestive essay of Mr. C. R. Van Hise on the metamorphism of sedimentary and igneous rocks, with especial reference to the pre-Cambrian series of North America, *16th Ann. Rep. U.S. G. S.* (1896), pp. 683, 715.

[2] See especially Lehman's 'Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine,' where the development of sericite as a result of mechanical deformation is well enforced.

[3] Rosenbusch, 'Mikrosk. Phys.' 2nd edition (1887), p. 185.

[4] J. J. H. Teall, *Q. J. G. S.* xli. (1885), p. 137.

[5] A. Schenck, 'Die Diabase der oberen Ruhrthals,' 1884.

[6] Hagge, 'Mikroskopische Untersuchungen über Gabbro,' &c. Kiel, 1871, p. 51.

grains of albite. Examples of this change may be found in association with the development of saussurite.[1]

Chloritisation—an alteration in which the pyroxene (or hornblende) of the so-called "greenstones" has been changed into secondary substances (1) more or less fibrous in structure allied to serpentine, not pleochroic but showing a decided action on polarised light; or (2) scaly, pleochroic, polarising so weakly as to appear isotropic, and more or less resembling chlorite. This alteration is rather the result of weathering than of metamorphism in the strict sense.[2] Where chloritization and epidotization have proceeded simultaneously in aluminous pyroxene or hornblende, the result is an aggregate of sharply defined pale yellow crystals of epidote in a green scaly mass of chlorite.[3]

Serpentinisation—an alteration more especially noticeable among the more highly basic igneous rock in which olivine has been a prominent constituent. The gradual conversion of olivine into serpentine has been already described (Fig. 32), and the occurrence of massive and schistose serpentine has been referred to (pp. 241, 243, 253).

Alterations of Titanic Iron.—The ilmenite or titaniferous magnetite of diabases and other eruptive rocks undergoes alteration along its margins and cracks into a dull grey substance (leucoxene, p. 97), which is a form of titanite or sphene. The grey rim frequently passes into well-defined aggregates and crystals of sphene.[4]

Marmarosis, or the alteration of an ordinary dull limestone into a crystalline-granular marble (p. 772) may be again referred to here as one of the characteristic transformations in regional metamorphism.

Dolomitisation.—The conversion of limestone into dolomite has been already referred to as taking place at present at ordinary temperatures in shallow oceanic waters and salt-lakes (pp. 426, 530). As illustrations of this change reference may be made to the upraised Tertiary and other limestones of Christmas Island in the Indian Ocean, which have had their organisms almost completely obliterated in consequence of dolomitisation, the rocks having recrystallised.[5] It may be difficult or impossible to decide whether the extensive conversion of original limestone into dolomite in tracts of regional metamorphism is to be regarded as the result of some similar early operation in sea-water, or as due to some more deep-seated and later transformation. The marmarosis of dolomites must be distinguished from their original texture.

Granitisation. See pp. 728, 781.

Production of New Minerals.—Tracts of regional metamorphism are characterised by the abundant appearance of new minerals, which in many cases are the same as those found in zones of contact-metamorphism, but reach a much greater development. All the distinctive minerals of the crystalline schists are examples of this recrystallization—quartz, orthoclase, microline, oligoclase, and other felspars, muscovite, biotite, hornblende, pyroxene, garnet, cordierite, sillimanite, andalusite, epidote, apatite, zircon, rutile, iron-ores, graphite, and many more. In the coarser gneisses some of these minerals attain large dimensions, especially among the pegmatitic veins, plates of mica and crystals of hornblende sometimes exceeding a foot in length.

It has been remarked also that not only is there a close similarity in the range of new minerals produced in regional and in contact-metamorphism, but the order in which they follow each other through increasing phases of alteration appears to be broadly alike in both cases. This similarity is especially conspicuous in the earlier stages. In more advanced alteration the rearrangements and recrystallizations are carried out on a much greater scale in regional metamorphism. After Zirkel had shown

[1] Lossen, *Jahrb. Preuss. Geol. Landesanst.* 1883, p. 640; 1884, pp. 525-530. Duparc et Pearce, *Compt. rend.* 8th Jan. 1900.

[2] Rosenbusch, 'Mikroskopische Physiographie,' pp. 180-184.

[3] G. H. Williams, *Bull. U.S. G. S.* No. 62, p. 56.

[4] A Cathrein, *Zeitsch. Kryst. und Mineral.* vi. (1882), p. 244.

[5] Andrews, 'Christmas Island,' p. 271.

in 1871 that in some of the clay-slates of disturbed Silurian and Devonian formations microscopic acicular microlites had been developed, considerable diversity of opinion arose as to their nature and origin. They were variously regarded as rudimentary crystallizations of hornblende, rutile, epidote or other mineral. E. Kalkowsky carefully isolated, extracted, and analysed them from a number of slates and regarded them as staurolite, constituting from two to five per cent of the rock.[1] The whet-slate of Belgium was found by Renard to be characterised by the presence of abundant garnets. Microscopic tourmaline has likewise been detected among clay-slates, but probably the most generally diffused mineral among these microlites is rutile. The rocks in which these microlites occur can hardly be classed as metamorphic, and yet the presence in them of microscopic microlites and crystals shows that they have undergone some of the initiatory stages of metamorphism, by the development of new minerals. All that is known of the probable origin of these minerals, negatives the supposition that they could have been formed in the original sediment of the sea-bottom on which the organisms entombed in the deposits lived and died. For their production, a temperature and a chemical composition of the water would seem to have been required, such as must have been inimical to the co-existence in the same water of such highly organised forms of life as brachiopods and trilobites.

Besides the appearance of the microlites, one of the most marked of the early stages of regional metamorphism is characterised by the appearance of fine scales of some micaceous mineral (muscovite, biotite, &c.). As these micaceous constituents increase in number and size, they impart a silky lustrous aspect to the surfaces on which they lie parallel. In many cases, these surfaces are probably those of original deposit, but where rocks have been cleaved or sheared, the mica ranges itself along the planes of cleavage or shearing. The Cambrian tuffs of South Wales, of which the bedding still remains quite distinct, present interesting examples of the development of a mica along the laminæ of deposit.[2] The Dingle beds of Cork and Kerry, on the other hand, have been subjected to cleavage, and the mica appears along the cleavage planes, which have a lustrous surface. The Torridonian and Cambrian sandstones, quartzites and shales of north-west Scotland show a development of mica along the surfaces of the shearing-planes.

A few illustrative examples of regional metamorphism, culled from different quarters of the globe, and various geological formations, may here be given. The subject is further discussed in Book VI. Part I.

Scottish Highlands.—This region, consisting mainly of crystalline schists, stretches through four degrees of latitude and four and a half of longitude, and thus covers an area of not less than 16,000 square miles. As, however, these rocks sink beneath later formations, and are prolonged into Ireland, their total area must be still more extensive. Probably no other tract of similar size and geological structure has been worked out in such detail and traced upon maps on so large a scale. It was the first large area of schistose rocks where the dislocations and other movements connected with regional metamorphism were followed out into their smallest proportions, and where the tectonic structure of such an area was fully unravelled. It may therefore serve as a typical region for the study and explanation of the phenomena of metamorphism, in so far as these have been attendant on the deformation and rupture of the terrestrial crust. But it possesses a further advantage, inasmuch as it displays many eruptive rocks which have been intruded since the general foliation, and which have produced a

[1] *Neues Jahrb.* (1879), p. 382. These bodies are to be distinguished from the minute crystals of heavy, durable minerals (zircon, rutile, &c.), so common as clastic grains in sediments, which, representing the detritus of older crystalline rocks, may often have played a part in the sedimentation of more than one geological period (pp. 163, 179).

[2] *Q. J. G. S.* xxxix. (1883), p. 310.

marked contact-metamorphism of the schists already metamorphosed by the earlier movements.

In beginning the study of this complicated but profoundly instructive territory, the student will find that in the north-western counties of Sutherland and Ross he can reach a tract that lay beyond the reach of the intense disturbances which prevailed farther to the east and south. He can there readily see, in a series of magnificent natural sections, the very oldest undisturbed rocks in Western Europe followed in consecutive order by those of later date, each in its normal position. He is thus put in possession of the order in which the formations were laid down, of their unchanged mineral characters, of their unconformabilities and other relations, and he obtains the key which will enable him to follow the intricate complications of the ground lying to the east. The various rocks here referred to will be described in their proper places in later parts of this volume (Book VI. Part I. § ii., Part II. Sect. i. § 2). For the present we are only concerned with their broad characters and their sequence.

At the base of the whole pile of ancient formations lies a remarkably coarse crystalline gneiss (Lewisian, 1 in Fig. 344), with abundant pegmatite veins, and several systems of dykes. It is unconformably overlain by nearly flat brownish-red (Torridonian) sandstones, conglomerates and breccias (2), which in turn are surmounted unconformably by inclined beds of quartzite (3, 4), shales (5), calcareous grit (6), limestones and dolomites (7), the geological age of which is fixed by the occurrence of recognisable fossils in them. The quartzite is full of annelide-burrows; the shales contain *Olenellus*—the distinctive trilobite of the lowest Cambrian rocks; the limestone has yielded *Maclurea*, *Murchisonia*, *Ophileta*, *Pleurotomaria*, *Orthis*, *Orthoceras*, *Piloceras*, and many more forms, indicating Cambrian and possibly the very lowest Silurian horizons. The strata are generally crowded with carbonaceous worm-casts (the so-called "fucoids"). Along their western margin, these rocks are so little altered that they do not in any way deserve the name of metamorphic.

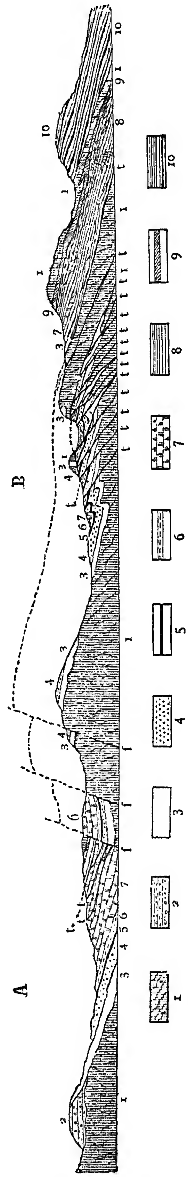

Fig. 344.—Diagram-section to show the geological structure of the North-West of Scotland.

10. Gneissose Flagstones, &c. } Newer or Eastern Gneiss ("Moine Schists.")
9. Siliceous schist . . . .
8. { Frilled schist . . . . / Green schist . . . . }
7. Durness-Eriboll Limestone and Dolomite — Cambrian, perhaps including part of Lower Silurian.
6. Serpulite Grit (*Salterella*) .
5. Fucoid-Beds (*Olenellus*) .
4. Piped Quartzite (*Annelids*) } Lower Cambrian.
3. { False-bedded Quartzite . / Basal Breccia . . . . }
2. Red Sandstones and Conglomerates . . } Torridon Sandstone.
1. Gneiss, Granite, Pegmatite, &c. . . } Lewisian Gneiss.

A, Durness Area, where the rocks are in their original position; B, Eriboll Area, where the rocks have been greatly plicated and fractured; f f, Normal Faults; t t, Reversed Faults and Thrust-planes; Dotted lines, continuation of normal Faults and Thrust-planes.

Eastwards, however, they pass under various schists and gneisses (8, 9, 10), which form a vast overlying, thoroughly crystalline series.

Already before the deposition of the Torridonian conglomerates and sandstones the Lewisian gneiss had undergone much deformation at successive periods of disturbance. During some of these movements its dykes suffered remarkable changes, being squeezed into a mere fraction of their breadth and sheared into various kinds of schist. It was from one of these dykes that, as far back as 1885, Mr. Teall demonstrated the production of hornblende-schist by the crushing down and recrystallization of dolerite.[1] All these examples of dynamo-metamorphism had ended long before the time of the Torridonian strata, which lie with an abrupt unconformability on the contorted gneiss and its network of dykes. The long period of quiet sedimentation represented by the thick Torridon sandstones was followed by an interval marked by another unconformability, and thereafter by the prolonged time required for the accumulation of the fossiliferous Cambrian strata. It was at some subsequent epoch that the earth-stresses manifested their effects anew in this region, and produced the regional metamorphism now to be described.

It was believed by Macculloch and Hay Cunningham that the fossiliferous quartzites of the north-west of Scotland truly underlie and are older than the eastern gneiss, which in many clear natural sections can be seen to repose conformably upon them. This natural view was adopted and worked out in some detail by Murchison, who extended his generalisation over the whole area of the Highlands, which he regarded as composed essentially of metamorphosed Silurian rocks (see p. 892). Other geologists supported Murchison, whose opinions met with general acceptance. Nicol subsequently contended that the overlying or "newer gneiss" is merely the old gneiss brought up by faulting. Later writers, particularly Professor Lapworth, Dr. Callaway, and Dr. Hicks, advanced somewhat similar opinions; but the difficulty remained of explaining how, if the "newer gneiss" is really older than the fossiliferous strata, it should overlie them so conformably as to have deceived so many observers. The problem was subsequently attacked independently by Professor Lapworth and by the Geological Survey, especially by Messrs B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Hinxman, and H. M. Cadell, and has now been solved.[2] I fully shared Murchison's belief in a continuous upward succession from the fossiliferous Lower Silurian strata into the overlying schists, but the subsequent detailed investigation of the ground convinced me that this belief could no longer be entertained.

Tracing the unaltered Cambrian strata eastwards from where they lie in their normal position upon the Torridon Sandstone and old gneiss below, we find them begin to undergo curvature. They are thrown into N.N.E. and S.S.W. anticlinal and synclinal folds which become increasingly steeper on their western fronts until they are disrupted, and the eastern limb of a fold is pushed over the western. By a system of reversed faults (t t in Fig. 344), a single group of strata is made to cover a great breadth of ground and actually to overlie higher members of the same series. The most extraordinary dislocations, however, are the Thrust-planes. These have so low a hade that the rocks on their upthrow side have been, as it were, pushed horizontally westwards, in some places for a distance of at least ten miles. But for the evidence of the clear coast-sections, these thrust-planes could hardly be distinguished from ordinary stratification-planes, like which they have been plicated, faulted, and denuded (dotted lines in the Fig.). Here and there an outlier of horizontally displaced Lewisian gneiss may be seen capping a hill of quartzite and limestone like an ordinary overlying formation.

The general trend of all the foldings and ruptures is N.N.E. and S.S.W., and as the steeper fronts of the folds face the west, the direction of movement has obviously been from the opposite quarter. That there has been an enormous thrust from the eastwards, is further shown by a series of remarkable internal rearrangements that have been

[1] "The Metamorphosis of Dolerite into Hornblende-schist," *Q. J. G. S.* xli. (1885), p. 133.

[2] The literature of this disputed question is fully given in the Report of the Geological Survey, *Q. J. G. S.* xliv. (1888), pp. 379-387.

superinduced upon the rocks. Every mass of rock, irrespective of lithological character and structure, is traversed by striated surfaces, which lie approximately parallel with those of the thrust-planes, and are covered with a fine parallel lineation running in a W.N.W. and E.S.E. direction. Along many zones near the thrust-planes, and for a long way above them, the most perfect shear-structure has been developed (Fig. 345). Thus here and there, where the unconformable junction between the gneiss and the conglomerate has come into one of the great lines of crushing, it has been rolled out, and the old structures of both rocks have been effaced. The gneiss has acquired a new foliation parallel to the shear-planes, and the conglomerate, with its pebbles turned round in the same direction, has had its paste converted into a schist, the foliation of which is parallel to that superinduced in the gneiss (Fig. 267). The coarse pegmatites in the gneiss have had their pink felspar and milky quartz crushed and drawn out into fine parallel laminæ, till they assume the aspect of a rhyolite in which fluxion-structure

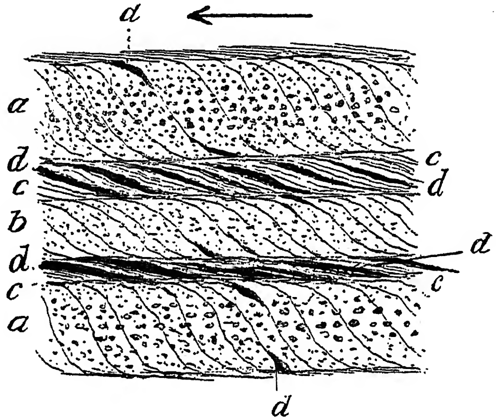

Fig. 345.—Diagram of altered Torridon sandstone, Coinne-mheall, Assynt.
a, Coarse grit or arkose; *b*, finer do.; *c*, shale; *d*, pegmatitic material developed as a consequence of the crushing of the rocks by movement in the direction of the arrow.

has been exceptionally well developed. Hornblende-rock passes into hornblende-schist. Sandstones, quartzites, and shales become finely micaceous schists. The annelide-tubes in the quartzite are flattened and drawn out into ribbands. New minerals, especially mica, and even aggregates of pegmatite (Fig. 345), have been abundantly developed along the superinduced divisional planes, and, in many cases, their longer axes are ranged in the same dominant direction from E.S.E. to W.N.W.

The whole of these rocks have undergone such intense shearing during their westward displacement that their original characters have in many cases been obliterated. Among them, however, can be recognised bands of gneiss which undoubtedly belong to the underlying Lewisian series. With these are intercalated lenticular strips of Cambrian quartzite and limestone. In some areas the Torridon sandstone has been heaped on itself, sheared and driven westward in large slices, the sandstones passing into sericitic schists and the conglomerates, as above remarked, having their pebbles flattened and elongated, while the matrix has become full of secondary mica. Some of the slices of rock thus disrupted and thrust westwards for distances of many miles are of gigantic size. Thus in the west of Inverness-shire those of moved Lewisian gneiss have been mapped by Mr. Peach over areas of more than 50 square miles without their limits being reached.[1] Eastwards, above one of the most marked and persistent thrust-planes,

[1] *Summary of Progress of Geol. Surv.* for 1898, p. 7.

the prevailing rock is a flaggy fissile micaceous granulitic gneiss or gneissose flagstone ("Moine-schist," p. 892). All these rocks have a general dip and strike parallel with those of the Cambrian strata on which they now rest, and in this respect, as well as in their prevailing lithological characters, they present the most striking contrast to the rocks that unconformably underlie the quartzites a little to the west. Whatever may have been their age and original condition, they have certainly acquired their present structure since Cambrian times.

From the remarkably constant relation between the dip of the Cambrian strata and the inclination of the reversed faults which traverse them, no matter into what various positions the two structures may have been thrown, it is tolerably clear that these dislocations took place before the strata had been seriously disturbed. The persistent parallelism of the faults, folds, and prevailing strike indicates that the faulting and tilting were parts of one continuous process. The same dominant north-easterly trend governs the structure of the whole Highlands, and reappears over the Silurian tracts of the south of Scotland and north of England. If, as is probable, it is the result of one great series of terrestrial movements, these must have occurred between the middle or close of the Cambrian period and that portion of the Old Red Sandstone period represented by the breccias and conglomerates of the Highlands. When the rocks were undergoing this metamorphism, there lay to the north-west a solid ridge of old gneiss and Torridon sandstone which offered strong resistance to plication (A in Fig. 344). The thrust from the eastward against this ridge must have been of the most gigantic kind, for huge slices, hundreds of feet in thickness, were shorn off from the quartzites, limestones, red sandstones, and gneiss, and were pushed for miles to the westward. During this process, all the rocks driven forward by it had their original structure more or less completely effaced. New planes, generally parallel with the surfaces of movement, were developed in them, and along these new planes a rearrangement and recrystallization of mineral constituents took place, resulting in the production of crystalline schists.

East of the line of Great Glen which cuts Scotland in two, crystalline schists form the eastern, central, and southern Highlands (Dalradian, p. 893). Though their order of succession cannot always be made out, they consist mainly of what were at one time sedimentary strata, with intercalated bands of igneous rocks which have likewise been foliated. The amount of metamorphism which they have undergone varies considerably from one part of the region to another. In the district of Loch Awe the shales, phyllites, grits, and limestones are hardly more altered than the fossiliferous Silurian formations of the south of Scotland,[1] and it is not too much to hope that they may yet yield organic remains. From this tract of minimum metamorphism we pass outwards through increasing phases of alteration until not far to the north-east the same strata became thoroughly crystalline schists. The stages which culminate in this transformation have been studied in the ground to the south-east, where the original sedimentary strata are found to have undergone a remarkable series of repeated movements. After having been thrown into folds and having undergone cleavage, thus receiving a first system of deformation, they afterwards suffered more than one repetition of the treatment. They consequently present secondary, tertiary, and perhaps even quaternary structures that may be ascribed to mechanical movement with accompanying recrystallization. The regional metamorphism thus produced cannot be traced to the influence of any igneous intrusion. It is not uniformly distributed, but seems to increase in intensity both from south-east and north-west towards a N.E. and S.W. line, which is an anticline of the foliation.[2]

Throughout the Central Highlands the rocks are as crystalline as any pre-Cambrian schists. Yet in many places unmistakable traces of clastic structure can be detected

[1] Mr. J. B. Hill, *Q. J. G. S.* lv. (1899), p. 470.

[2] "Geology of Cowal," Messrs. Clough and J. B. Hill, *Mem. Geol. Survey*, 1897.

among them. Thus they include bands of andalusite-slate,[1] of grits full of well-rounded fragments of quartz, felspar, or other ingredients, and even of coarse conglomerate, the large boulders of which (granite, gneiss, &c.) are wrapped round in a schistose matrix. At present there is no clear indication of the age of these rocks. The only fossils found in them are annelide burrows, which have been detected in the quartzites of Perthshire, Islay, and Jura. The limestones, of which two marked bands on different horizons traverse the Highlands from north-east to south-west, have in general become too crystalline to retain organic structures. Zones of graphitic schist can be followed for long distances, and often recall the black graptolitic shales of the Lower Silurian series. The officers of the Geological Survey have discovered, wedged in between the schists and the great boundary fault on the southern margin of the Highlands, a group of strata which present strong resemblance to some Lower Silurian rocks in the Southern Uplands of Scotland. They include certain cherts containing *Radiolaria*, and also some peculiar igneous rocks. They shade off so insensibly into the schistose series that no satisfactory line can be traced between them. If these strata are definitely identified as Lower Silurian, the conclusion may be drawn that the latest deformation of the Highland rocks took place after the Arenig period, and that these rocks probably include metamorphosed Silurian, Cambrian, and pre-Cambrian strata.[2]

The Scottish Highlands furnish further interesting material for the study of the problems of metamorphism, in the various eruptive rocks which they include. Thus in Banffshire and Aberdeenshire, large masses of diorite, diabase, and gabbro cut the schists in places, but run on the whole parallel with the general strike of the region. Their appearance, though later than that of the rocks through which they have come, was earlier than the regional metamorphism. The diorite has, in many places, itself undergone great alteration. Its component minerals have ranged themselves in the direction of the prevalent foliation, and where they have, probably originally, separated into distinct aggregates, the felspar forms a kind of labrador-rock, while the hornblende assumes the structure of perfect hornblende-schist. Numerous bosses of granite and porphyries likewise occur, traversing the diorites and schists and therefore of still later date. We have already seen (*ante*, p. 729) that in the Northern Highlands extensive tracts of schist have been "granitised" by the permeation of granitic material into them, and especially between their laminæ, whereby they have become highly crystalline gneisses. In the Southern Highlands also Mr. G. Barrow has found evidence that over and above the earlier widespread effects of great dynamical movements, a marked amount of metamorphism of the schists may be traced to the influence of younger erupted granites and gneisses.[3] He shows that a vast number of pegmatite veins which traverse the schists may be traced into bosses of intrusive granite or gneiss, the great mass of which is concealed below ground. He finds that three well-marked zones can be observed in the schists, of which the first, lying nearest to the main body of eruptive material, is marked by an abundance of sillimanite, the next by kyanite, and the outermost by staurolite. He has followed the same band of altered sedimentary material across these zones, which are thus shown to be entirely independent of the original structure of the rocks. These observations,

[1] It is important to note, as showing the relation of regional to contact-metamorphism that every stage in the development of the andalusite can be traced in these slates, though no eruptive rock appears at the surface. J. Horne, *Mineral. Mag.* 1884. I have proposed to class the metamorphic rocks of the Central and Southern Highlands by the name of Dalradian, for convenience of reference, until their true geological position shall have been determined. Address *Q. J. G. S.* (1891), p. 75, and *postea*, Book VI. Part I. § ii.

[2] See *Annual Reports of Geol. Survey* for the years 1893, 1895, 1896, and Summary of Progress for 1899, p. 67 ; G. Barrow, *Q. J. G. S.* lvii. (1901), p. 328.

[3] It has now been definitely ascertained that the younger granites of the south-west Highlands are later than the Lower Old Red Sandstone volcanic series of Lorne. *Summary of Progress of Geol. Surv.* for 1901.

which have been extended over many hundred square miles of Forfarshire, Perthshire, and Aberdeenshire, are of much interest and importance as they serve to connect the phenomena of contact and regional metamorphism.[1]

Scandinavia.—In many respects the geological structure of the Scandinavia peninsula is a prolongation of that of the Scottish Highlands. The general sequence of ancient rocks is broadly similar, and the manner in which they have been disrupted and metamorphosed closely resembles that which has been established in Scotland. Neither in Norway nor in Sweden has the same minutely detailed mapping been attempted, which has led to such successful results in the Highlands, but enough has been ascertained to show the general tectonic structure of the region and to afford additional material for the comprehension of regional metamorphism. A line drawn from south to north through the back-bone of Scandinavia divides the country into two great tracts, which are distinguished by this broad difference, that the western region has been the scene of gigantic movements of the terrestrial crust (p. 693), from which the eastern has been comparatively free. Hence the same formations on the two sides of the Peninsula present strongly contrasted aspects. These formations range from the most ancient (Archæan) gneisses through certain pre-Cambrian sedimentary groups of considerable thickness, then through representatives of the Cambrian, and Lower and Upper Silurian formations up to certain red sandstones, which are supposed to be stratigraphical equivalents of the Old Red Sandstone of Britain (pp. 898, 924). Along the eastern belt of territory the succession of the rocks is easily determined, for their distinctive petrographical characters remain, and the fossiliferous strata have yielded an abundant series of organic remains. In the western belt, on the other hand, owing to enormous horizontal displacements and numerous minor thrusts, the various rocks have been ruptured, and slices of them have been pushed over each other, while at the same time they have lost their original lithological aspect and have acquired more or less completely crystalline structures. The pre-Cambrian arkose known as Sparagmite is thus transformed westwards into various quartzose, micaceous, and hornblendic schists, according to its composition, and even into forms of gneiss. The Palæozoic formations can no longer be separated from each other, the shales and sandstones become transformed into various crystalline schists and quartzites, while the limestones are marmarised. Yet even among these intensely altered rocks organic remains have not been wholly effaced. In the year 1882 H. Reusch obtained from the Bergen district clear proof of the Silurian age of certain crystalline rocks in that part of Norway.[2] He found among masses of mica-schist, hornblende-schist, gneiss, and other crystalline rocks, intercalated bands of conglomerate which, while obviously of clastic origin, have undergone enormous compression, the pebbles being squeezed flat and the paste having become more or less crystalline. The occurrence of such bands would of itself suggest a sedimentary origin for a considerable part, if not for the whole of that series of deposits. But from several localities he obtained confirmation of this inference by detecting fossils which have been recognised as undoubtedly Upper Silurian. Some of them occur in a crystalline lime-

[1] G. Barrow, *Q. J. G. S.* xlix. (1893), p. 330.

[2] 'Silurfossiler og Pressede Konglomerater i Bergensskifrene,' Christiania, 1882, translated into German by R. Baldauf, 'Die fossilien-führenden krystallinischen Schiefer von Bergen in Norwegen,' Leipzig, 1883. The metamorphism of that district is proved to have been connected with powerful dynamical movements, the latest of which are of younger date than the Upper Silurian period. Prof. Brögger, in a valuable contribution to the discussion of the metamorphism of the Norwegian fjelds (No. 11 of the *Norg. Geol. Undersög.*, 1893), recognised the original character of some of the altered rocks, and to what subdivisions of the Palæozoic formations they belong. It is now admitted that the Cambrian and Silurian strata in the Hardanger section are not really continued upward into the overlying schists, as had been supposed, but that these schists have been driven over them upon a great thrust-plane. H. Reusch, J. Rekstadt, and K. O. Björlyke. *Op. cit.* Aarbog, 1902, No. 2. See *postea*, p. 970.

stone, which is intercalated in a dark lustrous phyllite. But they are found, as casts, most abundantly in a light-grey lustrous micaceous schist, which, under the microscope, is observed to be composed in large measure of quartz, not having a fragmental aspect, with mica, rutile, and tourmaline. The fossils recognised comprise *Phacops*, *Calymene*, several undeterminable gasteropods and brachiopods, *Cyathophyllum*, *Halysites catenularia*, *Favosites*, *Rastrites*, *Monograptus*, and some others. More recently abundant encrinites have been found in one of the schists among the high fjelds near Sulitelma on the Swedish frontier.[1]

Ardennes.—As far back as 1848, Dumont published a description of the Belgian Ardennes, in which he showed that a zone of his "terrains ardennais et rhénan," had undergone a remarkable metamorphism. Sandstones, in approaching this zone, were transformed, he said, into quartzites, and by degrees passed into rocks characterised by the presence of garnet, hornblende, and other minerals; the slates (phyllades) graduated into dark rocks, in which magnetite, titanite, and ottrelite had been developed. Yet the fossiliferous character of the strata thus metamorphosed had not been destroyed. In specimens showing a gradation from a grit to a compact garnetiferous and hornblendic quartzite, Professor Sandberger, to whom they were submitted, recognised the presence of the two Devonian shells, *Spirifer macropterus* and *Chonetes sarcinulatus*. "The garnets and the fossils are associated in the same specimen," he wrote, adding, "who, after this, can hesitate to admit that the crystalline schists and quartzites of the Hundsrück and Taunus are likewise metamorphosed Taunusian rocks ?"[2]

In 1882, M. Renard, fortified with the resources of modern petrography, renewed the examination of Dumont's metamorphic area of the Ardennes, and conclusively established the accuracy of all the main facts noticed by the earlier observer. Not only do the geological structure of this region, and the occurrence of recognisable fossils, show that the rocks, now transformed into more or less crystalline masses, were originally parts of the ordinary series of Devonian sandstones, greywackes, and shales, but the microscope comes in to confirm this conclusion. The original clastic grains of quartz and the diffused carbonaceous material of the unaltered strata can still be recognised in their metamorphosed equivalents. But there have been developed in them abundant new minerals—garnet (1 to 2 mm.), hornblende, mica, titanite, apatite, bastonite, ottrelite.[3]

Dumont appears to have believed that the metamorphism which he had traced so well in the Ardennes was to be attributed to the influence of underlying masses of eruptive rocks, though he frankly admitted that the metamorphism is less marked where eruptive veins have made their appearance than where they have not.[4] M. Renard, however, pointed out that eruptive rocks are really absent, and that the association of minerals proves that the metamorphosed rocks could not have been softened by a high temperature, as supposed by Dumont, otherwise the simultaneous presence of graphite

[1] H. Sjögren, *Geol. Fören. Stockholm*, xxii. (1900), pp. 105, 437. The structure of Scandinavia and the succession of its older rocks are more fully discussed in Book VI., pp. 898, 924. The effects of dynamo-metamorphism among the rocks of Scania have been described by H. Bäckström in his memoir on Vestanå, cited *ante*, p. 782. He thinks that they have more or less affected all the rocks of the district, but only here and there in strongly pronounced degree, while contact-metamorphism has been general among the sedimentary rocks. He points out that the youngest gneiss, with its overlying quartzite and tuff, which must once have covered an extensive area, has been in large measure removed by denudation, except where these rocks have been protected by a covering of the deeper seated and more highly metamorphosed gneisses which have been upthrust upon them.

[2] *Neues Jahrb.* (1861), p. 677.

[3] Renard (*Bull. Mus. Roy. Belgique*, i. (1882), p. 14) estimates the components of one of these altered rocks to be: graphite, 4·80; apatite, 1·51; titanite, 1·02; garnet, 4·14; mica, 20·85; hornblende, 37·62; quartz, 30·62; water, 1·32=101·88.

[4] Renard, *op. cit.* p. 34.

and silicates, with protoxide iron bases, such as mica, hornblende, &c., would certainly have given rise at least to a partial production of metallic iron. He connected the metamorphism with the mechanical movements which the rocks have undergone along the altered zone.[1] The metamorphism of this region was afterwards discussed by Professor Gosselet, who also regards it as due to dynamical causes.[2]

Taunus.—A similar example of regional metamorphism extends into the tracts of the Taunus and Hundsrück. In 1867 K. A. Lossen published an elaborate memoir on the structure of the Taunus, which is now of classic interest in the history of opinion regarding metamorphism.[3] He showed that below the middle Devonian limestone, the usual lower Devonian slates, greywackes, and quartzites rise to the surface, but that these, traced southwards, pass gradually into various crystalline schists. Among these schists, he distinguished sericite-gneiss, mica-schist, phyllite, knotted schist, augite-schist, sericite-lime-phyllite, quartzite, and kieselschiefer. As intermediate grades between these crystalline masses and the ordinary clastic strata, he observed quartz-conglomerates, with a crystalline schistose matrix, or with albite crystals, and quartzites with sericite or mica. He concluded that while these crystalline rocks present the most complete analogies with those of the Alps, Silesia, Brazil, &c., they are yet so intimately bound up alike petrographically and stratigraphically with strata containing Devonian fossils, and into which they pass by semi-crystalline varieties, that they must be considered as of Devonian age. Subsequently K. Koch proposed to regard the crystalline schists of the Taunus as Cambrian (Huronian),[4] and they have been indicated on the Geological Survey map as Cambrian or Silurian. But the fact that a conformable sequence can be traced from undoubted fossiliferous Devonian strata downwards into these crystalline schists makes it immaterial what stratigraphical name may be applied to them. They are almost certainly Devonian, as Lossen described them, and in any case, they are unquestionably the metamorphosed equivalents of what are elsewhere ordinary sedimentary strata.

The Alps.—In the geological structure of the central Alps, crystalline schists play an important part.[5] There can be no doubt that some parts of these schists represent

[1] *Op. cit.* p. 37.

[2] See his great Monograph on the Ardennes, *Mém. Carte Géol. France*, 1888, chap. xxv. More recently Professor Renard is inclined to think that at least some of the observed metamorphism may after all be due to igneous rocks concealed beneath; but this view is strenuously combated by Professor Gosselet, who gives several cogent reasons for his convictions. See *Bull. Soc. Belge Geol.* tome xii. (1898), pp. 214-220.

[3] "Geognostische Beschreibung der linksrheinischen Fortsetzung des Taunus," &c., *Z. D. G. G.* xix. (1867), p. 509 (1885), p. 29. E. Geinitz (*op. cit.* xxviii. 1876, p. 643) describes the occurrence of well-marked *Orthis* in a greenish hornblende-schist, consisting of quartz, hornblende, and octohedra of magnetite.

[4] See Lossen's reply, *Z. D. G. G.* xxix. (1877), p. 341. He argues convincingly against the supposition that these can be original chemical deposits of Cambrian age. (See also Renard, *Bull. Mus. Roy. Belg.* i. p. 31, *note.*)

[5] See Lory, 'Description géologique du Dauphiné' (1860), Part i. §§ 40-42; *Compte rendu Congrès Géologique International*, Paris, 1881, pp. 39-43; *Bull Soc. Géol. France*, 3e série, ix. (1881), pp. 652-679; Favre, 'Recherches géologiques dans les parties de la Savoie, &c., voisines du Mt. Blanc' (1867), chaps. xxi. xxiv. xxv.; A. Müller, *Mém. Soc. d'Hist. Nat. Bâle*, 1865-70; Sismonda, *Real. Acad. Sci. Torin.* (2), xxiv. (1866), p. 333; A. Michel-Lévy, "Chaines des Aiguilles Rouges," *B. Carte. Géol. France*, iii. (1892), No. 27; L. Duparc and L. Mrazec, "Massif du Mt. Blanc," *Mém. Soc. Phys. Hist. Nat.* Geneva, xxxiii. (1898), pp. 112-171; P. Termier, *B. Cart. Géol. France*, ii. (1891), No. 26, p. 75; M. Bertrand, *Compt. rend.* 1894, p. 212. The Palæozoic and Secondary age of part of the schists of the Alps is enforced by Heim, 'Mechanismus der Gebirgsbildung,' 1878; *Compt. rend. Congrès Géol. International, London* (1888), p. 16; *Nature*, xxxviii. (1888), p. 524;

what were once sedimentary strata, while others are not improbably altered forms of igneous rocks which were contemporaneously or subsequently intercalated among them. As regards their geological age, however, much diversity of opinion exists. Some writers claim them as of pre-Cambrian date, while others think that they may consist, perhaps in large measure, of Palæozoic or even younger rocks.

That a nucleus of crystalline schists already existed in the Alpine region before the deposition of the Carboniferous formations is abundantly clear. No one, for instance, can cross from Vernayaz in the Rhone valley by Fin Haut to the Col de Balme along the band of Carboniferous strata without encountering excellent sections of conglomerates, made up of the debris of the schists, and even lying on these rocks unconformably. The metamorphism which has so greatly affected the Palæozoic and Mesozoic formations of the central and eastern Alps is hardly appreciable in this part of the chain, for the Carboniferous conglomerates, though they have obviously been much crushed, cannot be called metamorphic, while the greatest change undergone by the carbonaceous shales is their alteration into silky phyllites. The Jurassic limestones that flank them likewise retain their blue tint and dull compact texture. Not far to the south, however, the continuations of the same strata have undergone more change, for at the well-known locality of Petit Cœur the plants so abundantly and admirably preserved in black schist have had their original substance replaced by a white hydrous mica.[1] Throughout the Alpine Carboniferous bands, where fossil plants occur, they usually show, by the extraordinary way in which they have been deformed, the intensity of the shearing stresses to which the rocks have been subjected.[2] It is in the eastern part of the chain, however, that the metamorphism of the Carboniferous bands appears to be most developed. A detailed investigation of the geotectonic and petrographical relations of these rocks was carried out in 1882 by the late D. Stur, Director of the Austro-Hungarian Geological Survey, and Baron von Foullon.[3] On the northern border of the Styrian Alps, near Leoben, a group of crystalline schists 10,000 to 13,000 feet thick reclines steeply (but it is said conformably) against gneiss. It consists of phyllite-gneiss, mica-schist, and chlorite schist, with four bands of dark graphitic schist and one or two seams of limestone. The plant-bearing graphitic schist is full of plant-remains (*Calamites ramosus*, *Pecopteris lonchitica*, *Lepidodendron phlegmaria*, &c.). The association of plants and the occurrence of bands of graphite, representative doubtless of former beds of coal, indicate that these carbonaceous rocks belong to the well-known Schatzler group of the lower Coal-series of Silesia. The whole succession of schists of which these plant-bearing beds are members, forms one continuous group, which Stur recognised as traceable for a long distance on the northern margin of the central range of the north-eastern Alps. He insisted that this group of schists cannot be the result of original chemical deposition, but, on the contrary, that it is shown, by a great series of facts, to be the metamorphosed equivalent of what, elsewhere, are unaltered Carboniferous strata. The distortion of the fossils, which proves that the rocks have behaved

Q. J. G. S. xlvi. (1890), p. 236 ; Grubenmann, *Mittheil. Thurganischen Naturf. Gesellsch.* Heft viii. (1888); Baltzer, 'Beiträge zur Geol. Karte der Schweiz,' No. 24 (1888). The volumes of these "Beiträge" contain ample details regarding the geological structure of the Swiss Alps. Professor Bonney holds that the crystalline schists of the Alps are older than the Palæozoic rocks, which even where altered can always, he thinks, be distinguished from true schists. Address, *Q. J. G. S.* vol. xlii. 1886, p. 66 ; xlv. 1889, p. 67 ; xlvi. 1890, p. 187 ; xlviii. 1892, p. 390 ; xlix. 1893, p. 89 ; l. 1894, pp. 279, 285 ; *Geol. Mag.* 1890, p. 533.

[1] Favre, 'Recherches Géol.' iii. p. 192.

[2] See Heer's 'Flora Fossilis Helvetiæ' (Steinkohlen Flora), Plate iv. Fig. 1 ; v. Figs. 1, 3 ; viii. Figs. 1, 2 ; xiii. Fig. 1, &c.

[3] *Jahrb. Geol. Reichsanst.* xxxiii. (1883), pp. 189, 207. See also Toula, *Verh. Geol. Reichsanst.* 1877, p. 240.

like plastic masses under the strain of mountain-making, the alteration of their substance into anthracite or graphite, and its replacement by micaceous silicates, are evidence of a serious metamorphism. Stur concluded that there was every encouragement to search for fossils in the schist envelope of the central Alpine gneiss.[1]

Baron von Foullon describes the petrographical characters of the various members of the group of schists in which the plants occur near Leoben. As to the thoroughly crystalline character of the phyllite-gneiss, mica-schist, &c., there can be no dispute. It will be enough here to refer briefly to the constitution of the graphite-schist in which the plants occur. Hand-specimens present a dull fracture, on which none of the components, except the graphite, can be recognised, though sometimes they show a greenish fibrous, asbestiform mineral. In thin slices, the rock is seen to be composed of quartz grains, chloritoid, an asbestos-like substance, and a mica, with abundant "clay-slate microlites," and diffused carbonaceous matter. It resembles the mica-chloritoid-schist of the Taunus. Some of the chloritoid-schists or quartz-phyllites associated with this plant-bearing band are also graphitic. Petrographical investigation thus concurs with the stratigraphical evidence to prove that a tract of crystalline schists in the north-eastern Alps consists of metamorphosed Carboniferous rocks. The evidence of intense mechanical movement and the absence of any indication of the influence of eruptive rocks combine to indicate that the metamorphism of these strata is an example of regional metamorphism.

In the western Alps the Triassic strata present greater evidence of metamorphism than the Carboniferous deposits which underlie them. In the chain of the Aiguilles Rouges near Chamounix, M. Michel-Lévy has observed that the arkoses of this series have been so crushed and altered that they can hardly be distinguished from the ancient crystalline schists. They have acquired a laminar structure with a recrystallization of sericite, chlorite, iron-ores, and quartz, and in this transformed condition alternate with bands where the alteration has not advanced so far.[2] The so-called "schistes lustrées" or "Bündnerschiefer" of the Alps are believed by those geologists who have most closely studied them to be metamorphic equivalents of some part of the vast series of formations between Archæan and Eocene. They have been so thoroughly modified as to possess in many places the wholly crystalline structure of mica-schist or hornfels. The following petrographical types are recognised among them: (1) micaceous calc-phyllite, sometimes containing fragmentary echinoderms; (2) calc-phyllite with zoisite, clintonite, or felspar and enclosing echinoderms, belemnites, and *Cardinia*; (3) black clintonite-phyllite with belemnites; (4) zoisite and garnet-phyllite with belemnites; (5) garnet and zoisite hornfels; (6) quartzless schist containing two micas, with kyanite, zoisite, epidote, and staurolite; (7) quartzose mica-schist with garnet, actinolite, staurolite, kyanite, epidote, zoisite, biotite, plagioclase, tourmaline, &c.; (8) actinolitic quartzite. Only in the first four types have fossils been found.[3] The

[1] He had, many years before this, announced his belief that the schistose envelope (Schieferhülle) of the Alps probably represents Palæozoic rocks. Stache, in 1874, stated that "the question now is how far Cambrian or Silurian rocks are represented," *Jahrb. Geol. Reichs.* 1874, p. 159. In 1884 he thought that the epicrystalline condition of the Silurian rocks in the Alps might be due to original crystalline precipitation. *Z. D. G. G.* 1884, p. 356. R. Hoernes has more recently published an excellent paper on the metamorphism of the Styrian graphite, in which he dwells upon the evidence for the regional metamorphism so well described by Foullon. He thinks that the transformation of the Rottenmanner granite into gneiss and the coal into graphite belong to one of the youngest periods in geological history, and form part of the late plication-movements of the Alps which, as shown in the frequent earthquakes, have not yet come to a state of rest. *Mitth. Naturwiss. Verein, Steiermark*, 1900, pp. 90-131.

[2] Michel-Lévy, *B. Carte. Géol. France*, iii. No. 27, p. 29.

[3] C. Schmidt, "Livret Guide dans la Suisse," *Congr. Géol. Internat.* 1894, p. 1[illegible].

metamorphism begins on the outer flanks of the Alpine chain and increases towards the central mountains. The Liassic shales by degrees become micacised and lose their fossils, while the limestones assume a jointed aspect and finally pass into a completely crystalline condition. In the Vaud Alps, the belemnites of the middle Oxfordian shales gradually disappear in proportion as the rock becomes more schistose, till at the Diablerets it is an almost crystalline sericitic schist.[1] The Eocene strata, also, under intense compression, have assumed the character of slates, which are worked for economic purposes.[2] Dr. Rothpletz, as the result of his study of the Bündnerschiefer of the central Alps, concludes that they comprise (*a*) marbles, dolomites, and calc-schists, of Archæan age, which alternate with true gneisses and mica-shists; (*b*) marbles, dolomites, calc-, clay-, and quartzite-schists, and diabase-schists of Palæozoic age; (*c*) dolomites, limestones, and schists, which are of Triassic age and lie unconformably on the Palæozoic series; (*d*) limestones, calc- and clay-slates, sandstones, and conglomerates, which in great part, if not entirely, belong to the Lias. The fossils in the Palæozoic series are indeterminable crinoid remains, those in the Triassic division cannot be specifically identified, but from the Liassic series a number of characteristic species of the Lower and Middle Lias have been obtained.[3]

Greece.—In the Grecian peninsula, vast masses of chlorite-schist, mica-schist, and gneiss occur, with thick interstratified zones of marble. In the calcareous zones fossils have been found which, though not well preserved, show that the rocks belong to the fossiliferous series of formations, and are not pre-Cambrian. These crystalline rocks in north-eastern Greece lie on the strike of normal Cretaceous hippurite limestones, sandstones, and shales, and are probably, at least in part, of Cretaceous age.[4]

Green Mountains of New England.—The Cambrian and Lower Silurian strata, which to the north in Vermont are comparatively little changed, become increasingly altered as they are traced southwards into New York Island. They are thrown into sharp folds, and even inverted, the direction of plication being generally N.N.E. and S.S.W. This disturbance has been accompanied by a marked crystallization. The limestones have become marbles, the sandy beds quartzites, and the other strata have assumed the character of slate, mica-schist, chlorite-schist, and gneiss, among which hornblendic, augitic, hypersthenic, and chrysolitic zones occur. The geological horizon of these rocks is shown by the discovery in them at various localities of fossils belonging to the *Olenellus* zone of the Cambrian and to the Trenton and Hudson River subdivisions of the Lower Silurian system of eastern North America. The rocks have been ridged up and altered along a belt of country lying to the east of the Hudson and extending north into Canada.[5] Since the observations of Dana cited below, the ground has been worked out in considerable detail by members of the Geological Survey of the United States. The Lower Cambrian age of the lower part of the great quartzite of Vermont is

[1] Renevier, *B. S. G. F.* (3), ix. (1881), p. 650; xvii. (1898), p. 884.

[2] Lory, *op. cit.* ix. (1881) p. 651.

[3] "Ueber das Alter der Bündnerschiefer," *Z. D. G. G.* 1895, i. pp. 1-59.

[4] M. Neumayr, *Jahrb. Geol. Reichsanst.* xxvi. (1876), p. 249. *Z. Deutsch. Geol. Ges.* xxxiii. pp. 118, 454. A. Bittner, M. Neumayr, and F. Teller, *Denksch. Akad. Wien*, xl. (1880), p. 395. R. Lepsius, in his great monograph 'Attika.' A useful compendium of information regarding the geology and physical geography of Greece will be found in the volume already cited, 'Physikalische Geographie von Griechenland, mit besonderer Rücksicht auf das Alterthum,' by C. Neumann and J. Partsch, Breslau, 1885.

[5] See Dana, *Amer. Journ. Sci.* iv. v. vi. xiii. xiv. xvii. xviii. xix. xx.; *Q. J. G. S.* 1882, p. 397. The identification of the so-called Taconic schists of New England with altered Lower Silurian rocks was called in question by Sterry Hunt, but the stratigraphical evidence collected by A. Wing, Dana, R. Pumpelly, J. E. Wolff, T. N. Dale, B. K. Emerson and others, and the testimony of the fossils collected by Dana, Dwight, Walcott, &c., have sustained it.

shown by the occurrence in it of *Olenellus*. The basement of the Cambrian series in Old Hampshire county, Massachusetts, is recognised by Professor Emerson in a gneissose conglomerate which graduates upward into the quartzite and lies unconformably on an older (Archæan) gneiss. Above the Cambrian quartzite the Lower Silurian formations are represented by a conformable series of sericitic, amphibolitic, chloritic, and other schists, which in turn are unconformably overlain by an upper group of quartzites, limestones, garnetiferous mica-schists and clay-slates, which are regarded as metamorphosed Upper Silurian strata.[1]

Menominee and Marquette Regions of Michigan.—In one of the most luminous essays yet published on the megascopic and microscopic proofs of dynamic metamorphism, to which reference has already been made (p. 790), G. H. Williams proved that a series of pre-Cambrian rocks of eruptive origin (greenstones, tuffs, agglomerates &c.) have been converted into perfect schists.[2] The various stages of alteration are minutely detailed, and careful drawings are given of the microscopic structures. The deductions arrived at by the author have far more than a mere local significance; they lay an accurate basis for the study of similar "greenstone-schists" in other regions, and show how the original eruptive character of such altered rocks is to be recognised.

It may be useful to group the foregoing and a few other examples of regional metamorphism in stratigraphical order, that the student may see over how wide a range of the geological formations such transformation has taken place.

Tertiary.—Northern and Central Italy.—Nummulitic limestone rendered saccharoid and strata (including Miocene) generally more indurated in proportion to the extent to which they have been folded and disturbed. These changes which indicate an incipient metamorphism are well displayed in the Apuan Alps and in the Apennines.[3]

Cretaceous.—Greece.—Chlorite-schist, mica-schist, marble, serpentine, &c., believed to be altered Cretaceous sandstone, shale, limestone, &c. (p. 803).

Coast range of California.—Strata containing Cretaceous fossils pass into jaspers siliceous slate (phthanites), glaucophane-schist, garnetiferous mica-schist, serpentine, &c.[4]

Jurassic.—Alps.—Sericite-schists, altered limestones, &c. (p. 803).

Sierra Nevada (California).—Clay-slates, talcose slates, serpentine, &c., passing into rocks containing Jurassic fossils.[5]

Trias.—Sierra Nevada (Spain).—Clay-slate, mica-schists, talc-schists, and limestones. Italy (Carrara, &c.).—Mica-schist, talc-schist, marbles, passing down into limestones containing *Encrinus liliiformis*, *Phylloceras*, *Pentacrinus*, below which lie gneissic and other schists enclosing *Orthoceras*, *Actinoceras*, and evidently of Palæozoic age.[7]

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[1] Messrs. Pumpelly, Wolff, and Dale, 'Geology of the Green Mountains in Massachusetts Monograph xxiii. of *U.S. Geol. Surv.* 1894; B. K. Emerson, 'Geology of Old Hampshire County, Massachusetts,' Monograph No. xxix., 1898.

[2] *Bull. U.S. Geol. Survey*, No. 62, 1890.

[3] Lotti and Zaccagna, *Boll. Comit. Geol. d'Italia*, 1881, p. 5. Lotti, *ibid.* p. 419 *B. S. G. F.* xvi. (1888), p. 406.

[4] Whitney, *Geol. Surv. California*, "Geology," vol. i. p. 23. G. F. Becker, *B. U.S. G. S.* No. 19 (1885); *Amer. Journ. Sci.* xxxi. (1886), p. 348. "Geology of the Quicksilver Deposits of the Pacific Slope," Monograph No. xiii. of *U.S. Geol. Survey*, 1888.

[5] Whitney, *op. cit.* p. 225. J. S. Diller (*B. U.S. G. S.* No. 33, 1886), accepting the general view that at least a portion of the auriferous slates is Mesozoic, suggests that part of them may be Carboniferous, or even older.

[6] De Verneuil, *Bull. Soc. Géol. France* (2), xiii. p. 708. R. von Drasche, *Jahrb. Geol. Reichsanst.* xxix. (1879), p. 93. The identification of these rocks with Triassic beds is probable conjecture.

[7] Coquand, *B. S. G. F.* (3), iii. p. 26; iv. p. 126. Zaccagna, *Boll. Com. Geol. Ital.* xi (1881), p. 476. Lotti, *op. cit.* p. 419, Plate ix. S. Franchi, *op. cit.* 1898, Nos. 3 and 4.

Alps.—Limestones, dolomites, and gypsums rendered crystalline, associated with calc-mica-schist and other varieties of schist (p. 802).

Punjab.—Infra-Triassic rocks overlain by a series of gneisses and schists.[1]

Carboniferous.—Alps.—Graphite-schist, phyllite-gneiss, &c. (p. 801).

Eastern Brittany.—Carboniferous shales altered into crystalline schists.[2]

Devonian.—Taunus.—A large series of crystalline schists (p. 800).

Ardennes.—Crystalline schists with garnet, hornblende, mica, &c. (p. 799).

Silurian and Cambrian.—Scotland.—A great series of crystalline schists overlying quartzite and limestones with fossils (p. 792).

Norway.—A series of schists resembling those of Scotland, lying upon and interstratified with fossiliferous beds (p. 798).

Green Mountains of New England.—A great group of schists, quartzites, and limestones, with fossils in some beds (p. 803).

Saxon granulite tract.—Schists, schistose conglomerates, &c.[3]

South Wales.—A fine foliation of the tuffs, representing an early stage of regional metamorphism.[4]

Pre-Cambrian (Archæan).—Scotland.—Sandstone and arkose passing into lustrous crumpled micaceous schists (p. 794). Some of the Archæan gneisses and hornblende rocks of Sutherland have had a new schistosity superinduced in them by the shearing movements that altered the Cambrian strata (p. 885, *seq.*).

Michigan.—Eruptive rocks converted into schists (see above). Conglomerates with elongated pebbles in a matrix of sericite-schist.[5]

Summary.—From the evidence now adduced the following conclusions may be confidently drawn.

1. There are wide regions in which crystalline schists (*a*) overlie fossiliferous strata, or (*b*) contain intercalated bands in which fossils occur, or (*c*) pass either laterally or vertically into undoubted sedimentary strata.

2. These schists are in some cases the metamorphosed equivalents of what were once ordinary sedimentary deposits, with frequently included igneous rocks.

3. The alteration by which rocks have been affected in regional metamorphism is, on the whole, similar in its stages to what may be traced in local metamorphism round bosses of granite, but has attained a much greater development.

4. Regional metamorphism has been directly connected with (*a*) enormous pressure leading to little or no molecular crushing, but with some shearing movement in the rock; or (*b*) with intense compression or tension, under which much shearing and rupture have taken place. The former or statical phase does not produce such striking results as the latter or dynamical phase. The metamorphism is usually most pronounced where, as shown by plication, puckering, and shear-structure, the rocks have been subjected to the greatest mechanical movement.

5. The dynamical stresses have been generally, perhaps always, accompanied with more or less chemical reaction, not, as a rule, involving the introduction of new chemical constituents, but consisting chiefly in a recombination of those already present in the rocks, with the consequent development of new crystalline minerals.

[1] A. B. Wynne, *Geol. Mag.* 1880, p. 314.

[2] Jannettaz, *Bull. Soc. Géol. France* (3), ix. (1881), p. 649.

[3] Lehmann's work cited *ante*, p. 785.

[4] *Q. J. G. S.* xxxix. (1883), p. 310.

[5] T. M. Clements, H. L. Smyth, and W. S. Bayley, "The Crystal Falls Iron-bearing District," 19*th Ann. Rep. U.S. G. S.* 1899. See also the paper by C. R. Van Hise cited *ante*, p. 790.

6. This chemical and mineralogical rearrangement has probably been superinduced under the influence of moderate heat, and in presence of water, and is comparable with what, on a feeble scale, can be achieved in the laboratory.

7. The alteration of rocks in an area of regional metamorphism is often strikingly unequal in degree even over limited areas, being apt to attain sporadically a maximum intensity, particularly in tracts of greatest shearing or plication, while in other areas, the original clastic or crystalline characters may be easily discernible.

8. The nature of the alteration has depended first, and chiefly, on the original character and structure of the rocks affected by it; and secondly, on the nature and intensity of the metamorphic activities. Of some rocks (sandstone, carbonaceous shale, coal), the original condition may be recognisable when that of their associated strata has entirely disappeared.

9. The foliation in a tract of regional metamorphism has been developed along divisional planes which guided the crystallization or rearrangement of the minerals. In some cases, these planes coincide with those of original deposit. In others, they may represent cleavage, as was long ago pointed out by Sedgwick and Darwin. Or they may indicate the planes along which, under intense pressure, the longer axes of crystallizing minerals would naturally range themselves. In a rock, homogeneous in chemical composition and general texture, foliation might be induced along any dominant divisional planes. If these planes were those of cleavage or of shearing, the resultant foliation might not appreciably differ from that along original bedding planes.[1] But it may be doubted whether a cleavage foliation of clastic sedimentary strata could run over wide areas without sensible and even very serious interruptions. In most large masses of sedimentary matter, the usual alternations of different kinds of sediment could not but produce distinct kinds of rock under the influence of metamorphic change. Where foliation coincides with cleavage over large tracts, it will almost certainly be crossed by bands, more or less distinct, coincident with the original bedding, whether of sedimentary or of eruptive rocks, and running oblique to the general foliation, as bedding and cleavage do, save where they may happen to coalesce. Where a massive rock of generally homogeneous composition, such as a felsite or granite, has been intensely sheared, a rearrangement or recrystallization of its minerals has taken place along the planes of shearing. Such a rock is thus transformed into a schist. Even rocks of much more varied structure, like Archaean gneisses, have been subjected to such changes from shearing as not only to lose entirely their original structure, but to acquire a new foliation parallel to the shearing planes (p. 888).

It is now generally agreed that many gneisses and other forms of schist have been formed by dynamical action out of deep-seated masses of igneous rocks, both acid and basic. The banding of these rocks, which was formerly regarded as evidence of aqueous deposition, is no

[1] Jannettaz points out that the cleavage of the slates in the Grenoble Alps is parallel to the foliation of the mica-schists. *Bull. Soc. Géol. France* (3), ix. (1881), p. 649.

doubt generally due to an original segregation or differentiation of the component minerals of still unconsolidated igneous rocks, like the banded structure of some gabbros, though it may to some extent have resulted from the rearrangement and recrystallization of the materials of such rocks under intense mechanical strain. The occurrence of lenticular bands or bosses of amphibolite in coarse or granitoid gneiss probably indicates dykes of some pyroxenic or hornblendic rock, by which the original granite was traversed before the development of the foliated structure. A gradation can be traced between masses of diorite, gabbro, &c., and hornblende-schists, actinolite-schists, gabbro-schists, &c. The granitoid character of these basic igneous rocks, under the great stresses they have suffered during periods of terrestrial disturbance, has here and there entirely disappeared. First the minerals (especially the felspars) are seen to have ranged themselves with their long axis in one general direction. They have further separated into layers or folia in the same direction, and have thus acquired a more or less distinctly foliated structure. A massive diorite, gabbro, or diabase has in this way been converted into an amphibolite-schist.

PART IX. ORE-DEPOSITS.[1]

Metallic ores and other minerals that are extracted for their economic value occur in certain well-marked forms which have been variously

[1] A large list of works on the subject of Ore-Deposits might be cited here. The following selection includes some of the more important text-books and memoirs, while others are referred to in subsequent pages. In English, J. A. Phillips' work, mentioned *ante*, p. 7, has long been a standard text-book. Another valuable treatise, "The Genesis of Ore-deposits," is based on an original memoir, by Posepny, with additions by American authorities, 2nd edit., 1902. Other general text-books are B. von Cotta, 'Die Lehre von Erzlagerstätten,' 1859-61; A. von Groddeck, 'Die Lehre von den Lagerstätten der Erze,' 1879; F. von Sandberger, 'Untersuchungen über Erzgänge,' 1882-1885; R. Beck, 'Die Lehre von Erzlagerstätten,' Berlin, 1901; E. Fuchs and L. Delaunay, 'Gites Mineraux,' Paris, 1893. The *Transactions of the Royal Geological Society of Cornwall* contain many good papers.

So much mining activity has been developed in the United States that the subject has there been studied in much detail, and great additions to our knowledge have been made by the writings of Newberry, Le Conte, Becker, Emmons, Kemp, Van Hise, Lindgren, and other geologists. The *Transactions of the American Institute of Mining Engineers* are full of excellent contributions. The general subject of the ores of the United States is treated by Professor Kemp in his 'Ore Deposits of the United States,' of which a third and entirely rewritten edition was published in 1900. The most elaborate accounts of the mining regions of the States, with discussions of some of the problems presented by them, are given in the quarto monographs of the *United States Geological Survey* as follows: G. F. Becker, 'Geology of the Comstock Lode,' Mon. iii. iv. and xiii. (also in *8th Ann. Rep.* 1886-87, p. 695); R. D. Irving, 'Copper-bearing Rocks of Lake Superior,' Mon. v.; Curtis, 'Silver-lead deposits of Eureka, Nevada,' Mon. vii.; S. F. Emmons, 'Geology and Mining Industry of Leadville, Colorado,' Mon. xii.; 'Geology of the Quicksilver Deposits of the Pacific Slope,' Mon. xiii.; Irving and Van Hise, 'The Penokee Iron-bearing Series of N. Wisconsin,' &c. Mon. xix.; Van Hise and Bayley, 'The Marquette Iron-bearing District of Michigan,' Mon. xxviii.; Spurr, 'Geology of the Aspen Mining District of Colorado,' Mon. xxxi.; Clements, Smyth, Bayley and Van Hise, 'The Crystal Falls Iron-bearing District of Michigan,' Mon. xxxvi.; "The Gold-

classified; but for the purposes of the geological student it is most convenient to consider them from the point of view of geological origin and structure. Thus arranged, they naturally group themselves into three great series: 1st, those connected with the ascent of a molten magma into the crust of the earth; 2nd, those which have been introduced in solution into fissures, and have no obvious connection with the protrusion of any magma; and 3rd, those which have been contemporaneously deposited in superficial formations.

1. Magmatic Ores.—They may arise either (*a*) from differentiation within the magma itself, or (*b*) from pneumatolitic action, whereby the metallic constituents of the magma are carried beyond the magma into the surrounding rocks.

(*a*) So far as experience goes, metallic concentration has comparatively seldom taken place on a large scale within those portions of eruptive masses of rock now visible at the surface, though some remarkable examples of it have long been known. It is more particularly observable among the basic rocks, where magnetic and titaniferous iron have made their appearance among the latest products of segregation within the intruded magma In banded gabbros, for instance, some of the dark layers are in large measure made up of iron ores. The great Norwegian aggregates of titaniferous iron are found in basic igneous rocks (labradorite-rock, norite, gabbro, &c.), and even penetrate the adjacent formations as intrusive dykes.[1] In Canada also large masses of titaniferous magnetite in like manner belong to a great series of basic eruptive rocks and form groups of hills.[2] The segregation of chromite in peridotites is another example of the same process.[3] Subsequent extreme terrestrial disturbances have in the case of the most ancient ore-bodies of this kind imparted a schistose structure to the igneous rock, so that the ores now appear intercalated among gneisses and crystalline schists.

(*b*) Much more frequent is the accumulation of ores in fissures and other cavities among the rocks that surround a large eruptive mass. The connection between such ores and an adjacent plutonic intrusion is so frequent and obvious that it cannot be regarded as accidental. It clearly points to a genetic relation between the metals and the intrusive rock,

quartz Veins of Nevada City and Grass Valley, California," 17th *Ann. Rep. U.S. G. S.* Part ii. (1896), pp. 13-269; W. Lindgren, "The Gold and Silver Veins of Idaho," *20th Ann. Rep. U.S. G. S.* Part iii. (1900), pp. 65-256; the same volume contains a long paper by Messrs. Weed and Pirsson on similar phenomena in Montana, pp. 271-581. Messrs. Hatch and Chalmers have described 'The Gold Mines of the Rand,' London, 1895. Among the contributions of a theoretical kind Professor Vogt's papers deserve careful perusal. They will be found in *Geol. Fören. Stockholm*, xiii. (1891), pp. 476, 683; xiv. p. 212 (pneumatolytic processes in gabbro); pp. 315, 433; xvi. 275; *Zeitsch. Prakt. Geol.* 1893, 1894, 1895, 1898, 1899, 1900, 1901; *Trans. Amer. Inst. Min. Engin.* 1901; *Compt. rend. Congr. Geol. Internat.* Zurich, 1894, p. 382; *Norges Geol. Undersög.* 1892.

[1] Vogt, *Norges Geol. Undersög*, 1892.

[2] F. D. Adams, *Neues Jahrb.* Beilag, Bd. viii. p. 419; *Min. Assoc. Quebec.* 1894. See also J. F. Kemp, *School of Mines Quarterly*, New York, July and November 1899.

[3] Vogt ("Problems in the Geology of Ore Deposits"), *Trans. Amer. Inst. Min. Engin.* 1901), who cites other illustrations, though he thinks that the list can never become large.

and indicates that the agents by which their separation was effected were those mineralising vapours and gases which have been so often alluded to in previous pages of this text-book. Steam or water-gas at a high temperature and great pressure has no doubt been largely instrumental in the transference of the ores. Thus around large bosses of granite, the steam, charged with compounds of fluorine, boron, and phosphorus, has carried over from the still unsolidified granite the tin-ore which, with its accompanying minerals, is such a characteristic metal in the surrounding veins. Again, next to large masses of gabbro veins of apatite are sometimes conspicuous, as in Norway and Northern Sweden. Professor Vogt has shown reason to believe that in each case the material that fills the veins was probably extracted from the magma by a reaction, in the presence of water, of hydrochloric (or, as the case may be, hydrofluoric) acid dissolved in the magma. The mineral veins which can be ascribed to this process may extend to a horizontal distance of a mile or more from the eruptive mass, but still lie within the areole of contact-metamorphism. They often appear at or close to the boundary of the eruptive mass, and even when at their greatest horizontal distance from its outcrop they may not improbably be much nearer to it in vertical descent below. These features are characteristically displayed in such mining districts as Cornwall, Southern Hungary, Elba, and Christiania. The ores consist of magnetite, specular iron, cassiterite, sulphides of copper, lead, zinc, &c.

2. Solution Ores.—Though no satisfactory division can be made between these and those last described, it is useful to keep by themselves those ore-deposits which stand in no obvious relation to any eruptive mass visible at the surface, though of course many of them may be connected with deep-seated igneous masses, which have not been exposed. Much diversity of opinion still exists as to the source of the metal in these accumulations. Of the various theories that have been proposed the following are the most noteworthy: (1) Lateral segregation, whereby the substances in the veins have been derived from the adjacent rocks by a process of leaching or solution and redeposit, carried on by the circulation of water through the terrestrial crust. The fact that the nature and amount of the minerals, and especially of the ores, in veins, so often vary with the composition of the surrounding rocks is dwelt on by those who hold this view as a proof that these rocks have had an influence on the precipitation of mineral matter in the fissures passing through them, and were probably themselves the source from which the metals were obtained. It is pointed out that chemical analysis has revealed the presence of minute quantities of metallic ores dispersed through the substance of the rocks surrounding mineral-veins, that by isolating some of the more frequent silicates found as rock-constituents (such as augite, hornblende, and mica), iron, nickel, copper, cobalt, arsenic, antimony, tin, &c., have been found in appreciable quantity, and that stratified rocks also, when subjected to sufficiently delicate analysis, reveal the presence in them of the metals and non-metallic substances that constitute mineral-veins; clay-slates, for example, having been found to

contain copper, zinc, lead, arsenic, antimony, tin, cobalt and nickel.[1] It is further argued that only on the assumption that the water is of meteoric origin and belongs to the outer part of the crust, can the fact be explained that mineral-veins are so often found to become thinner and poorer as they are followed downward. It is likewise maintained that below an extreme depth of some 10,000 metres, or seven or eight miles, the pressure must be so great that no fissure can remain open, but if formed by any great disturbance of the crust must be immediately closed again. There can indeed be little doubt that a vast amount of solution and redeposit of mineral matter within the crust of the earth must be effected by the circulation of meteoric water, some of which may have its energy increased by the earth's internal heat, and that fissures may thus conceivably be filled up with new mineral deposits. But strong objections have been urged against this explanation as a general theory of the origin of mineral veins. The frequent association of mineral veins with ancient protrusions of eruptive material and with modern volcanic action, the generally observed dryness of deep mines which appear to descend below the usual limit of the circulation of ground-water, and the continuance of mineral veins down through those dry parts of the crust as far as mining operations have been carried, are urged as inexplicable on the supposition that meteoric water is the only or even the chief source from which mineral veins have been supplied.

(2) Ascent from below—the minerals and ores having been introduced by (*a*) sublimation, or (*b*) by igneous fusion, or (*c*) by hot aqueous vapour escaping from the magma underneath. Sublimation takes place in the upper part of a volcanic chimney, among the crevices into which the hot vapours and gases enter, but has probably played little or no part in the formation of mineral veins. Igneous injection may take place at the edge of an igneous mass, as in the case of magmatic segregations like those of the titaniferous iron-ores above referred to in connection with the differentiation of gabbro and allied rocks. But the most cursory acquaintance with ordinary mineral-veins suffices to assure us that in their production the injection of igneous material can have had no share.

We are thus left with only the heated solutions that escape from the internal magma through such fissures as may be opened in the overlying crust. To the objection that such fissures cannot exist save in the outer few thousand metres of the crust, it may be answered that while our knowledge of the conditions of the earth's interior is not such as to warrant us in fixing a limit to the downward extension of fissures, we do not need to suppose them to descend any deeper than to come within the influence of the magma. We are absolutely ignorant at what depth this magma may be reached at any one part of the earth's surface; but we do know that at volcanic vents it actually comes up to the surface and

[1] This view of the subject has been espoused and exhaustively discussed by Professor F. Sandberger in his 'Untersuchungen über Erzgänge,' Part i. It is also cogently supported by Mr. Van Hise, *Trans. Amer. Inst. Min. Engin.* xxx. (1900); *Journ. Geol.* viii. (1900), pp. 730-770; and has recently been discussed by Mr. W. H. Weed, *Amer. Geol.* xxi. (1902), p. 170.

sometimes rises, as in Cotopaxi, 19,000 feet above it. There does not therefore appear to be any insuperable difficulty in the assumption that the heated vapours of the magma may find their way up rents in the crust even when the magma itself has been unable to follow them. That the hot waters which rise from the interior, especially in volcanic districts, bring up to the surface mineral solutions such as those that must have been in operation for the infilling of mineral veins, admits of no doubt. Various minerals, including silica, both crystalline and chalcedonic, metallic sulphides, and even metallic gold, are held in solution and deposited by the hot waters of California and Nevada, where metalliferous lodes may thus be in course of formation at the present day.[1] In the solfatara of Lake County, California, the sulphur contains cinnabar, and the rocks through which the waters issue are coated with gelatinous silica resting on chalcedony, beneath which lies crystalline quartz. Again, the hot waters of Steamboat Springs, Nevada, are now depositing gold, probably in the metallic state; sulphides of arsenic, antimony, and mercury; sulphides or sulpho-salts of silver, lead, copper, and zinc; iron-oxide and possibly also iron-sulphides; manganese, nickel, and cobalt compounds, with a variety of earthy minerals.[2] At a short distance from these springs, a group of fissures that still give off steam and carbonic acid have been filled with hyaline and crystalline silica. The quartz contains oxides of iron and manganese, sulphides of iron and copper, and traces of gold. A few miles distant is the famous Comstock Lode, which has evidently been formed in a similar manner by ascending hot water, and from which a vast amount of silver and gold has been obtained.

The obvious genetic relation between mineral veins and eruptive bosses, above referred to, and the association of the same peculiar minerals both in these veins and in the pegmatites that surround the bosses, justify the confident belief that, in these instances at least, the common source of all the minerals and ores has been the eruptive magma which furnished the intrusive masses, and likewise the vapours and mineralising agents that have affected all the surrounding rocks for a distance of a mile or more. If this intimate relationship can be established in the case of mineral veins which are connected with eruptive bosses that have by denudation been exposed at the surface, it is not illogical to infer that the same connection probably exists in the case of other veins which have no visible connection with any intrusive masses as yet revealed at the surface. Such masses may exist below at no very great depth. The general deduction, therefore, appears to me to be well founded, that while lateral segregation must be recognised as a possible contributing cause, the main agency in the formation of mineral veins is to be sought in the ascent of heated waters which could only have derived their pneumatolitic efficacy from the internal magma.[3]

[1] J. A. Phillips, *Q. J. G. S.* xxxv. p. 390. W. H. Weed, 21st *Ann. Rep. U.S. G. S.* Part ii. (1900) p. 217.

[2] G. F. Becker, *Amer. Journ. Sci.* xxxiii. (1887), p. 200.

[3] See a paper by Professor J. F. Kemp "On the rôle of the Igneous Rocks in the formation of Veins," *Contrib. Geol. Dept. Columbia Univ.* ix. (1901), No. 77. J. B. Hill,

As the solutions, in their ascent from below, reach cooler parts of the earth's crust, they doubtless begin to deposit their mineral contents on the walls between which they rise. In their progress they necessarily induce chemical and mineralogical changes in the surrounding rocks, which thus undergo various transformations, being sometimes weakened by the removal of certain constituents, as in propylitisation (p. 772) and kaolinisation (p. 104), and sometimes rendered more compact and crystalline by the introduction of new ingredients, as in the production of schorl-rock, topaz-rock and the felsparless rock known as greisen.[1]

3. Superficial ores in sedimentary deposits.—These are mainly of two kinds. (*a*) Formed of fragments of old ores which in the denudation of a region have been worn away, and of which the detritus is collected in different sedimentary deposits. Examples of this type are seen in the *placer* workings of gold in the alluvium of modern or ancient rivers and the *stream-works* in which tinstone sand is collected. (*b*) Formed by precipitation from aqueous solution, as in the deposits of bog-iron-ore and lake-ore, already described (p. 186). Ancient examples of this type prove that similar concentration and deposition has taken place in the waters of all geological periods, and that the agency of both plants and animals has contributed towards the elimination of the ores from aqueous solution. The ironstones of the Coal-measures and the Jurassic rocks of Britain and the copper-ores of the Kupferschiefer of Germany may be cited in illustration. Ores contemporaneously deposited in sedimentary strata obviously do not require separate consideration here, seeing that they are subject to the ordinary structures and variations of stratified rocks, which have already been discussed in Book IV. Part I. We may therefore restrict the following descriptions to those forms of accumulation which present peculiar structures, and which for their geological interest and economic importance merit more detailed notice.

§ i. Mineral-Veins or Lodes.

A true mineral-vein consists of one or more minerals deposited within a fissure of the earth's crust, and is usually inclined at from 10° to 20° from the vertical. The bounding surfaces of such a vein are termed walls, and, where inclined, that which is uppermost is known as the *hanging*, and that which is lowest as the *lying* or *foot* wall. The surrounding rock, through which veins run, is termed the country or country-rock. Mineral veins are composed of (*a*) masses or layers of simple minerals without metallic ores, or (*b*) of such minerals (termed *vein-stones*) intermingled or alternating with metallic ores. They are distinct from the surrounding rock, and are evidently the result of separate deposition. They are commonly most frequent and most

"The Plutonic and other intrusive Rocks of West Cornwall in their relation to the Mineral Ores," *Trans. Roy. Geol. Soc. Cornwall,* xii. (1901), Part vii.

[1] See W. Lindgren, "Metasomatic Processes in Fissure-Veins," *Trans. Amer. Inst. Min. Engin.* xxx. p. 578.

metalliferous in districts where eruptive rocks are abundant. A vein generally coincides with a line of fault or of joint, but is independent of the bedding or foliation of the "country." Cases occur among crystalline massive rocks, however, and still more frequently among limestones, where the introduction of mineral matter has taken place along gently inclined or even horizontal planes, such as those of stratification, and the veins then look like interstratified beds, or where the infiltration has proceeded along vertical lines, like igneous dykes or veins. Some remarkable examples of this form of interpenetration of mineral matter have already been noticed from the mining region of Cornwall (*ante*, p. 778).

Variations in breadth.—Mineral-veins vary in breadth from a mere paper-like film up to a great wall of rock 150 feet wide or more.

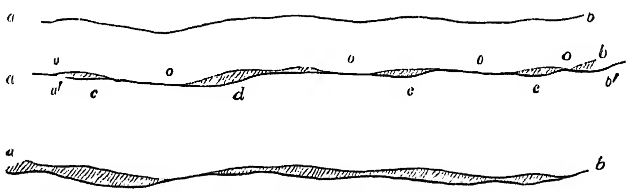

Fig. 346.—Widening of a fissure by relative shifting of its side (De la Beche).

The simplest kinds are the threads or strings of calcite and quartz, so frequently to be observed among the more ancient, and especially more or less altered, rocks. These may be seen running in parallel lines, or ramifying into an intricate network, sometimes uniting into thick branches and again rapidly thinning away. Considerable variations in breadth may be traced in the same vein. These may be accounted for by unequal solution and removal of the walls of a fissure, as in the action of permeating water upon a calcareous rock; by the irregular opening of a rent, or by a shift of the walls of a sinuous or irregularly defined fissure. In the last-named case, the vein may be strikingly unequal in breadth, here and there nearly disappearing by the convergence of the walls, and then rapidly swelling out and again diminishing. How simply this irregularity may be accounted for will be readily perceived by merely copying the line of such an uneven fissure on tracing paper and shifting the tracing along the line of the original. If, for example, the fissure be assumed to have the form shown at *a b*, in the first line (Fig. 346), a slight shifting of one side to the right, as at *a′ b′* in the second line, will allow the two opposite walls to touch at only the points *o o*, while open spaces will be left at *c c d*. A movement to the same extent in the reverse direction would give rise to a more continuously open fissure, as in the third line. That shiftings of this nature have occurred to an enormous extent in the fissures filled

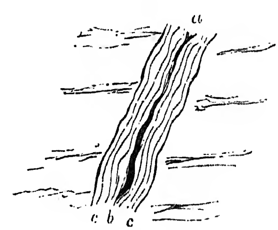

Fig. 347.—Section of a fissure nearly filled with one mineral (*c c*) but with a portion of the fissure (*a b*) still open (*B.*).

with mineral-veins, is shown by their abundant slickensides (p. 661). The polished and striated walls have been coated with mineral matter, which has subsequently been similarly polished and grooved by a renewal of the slipping.

Structure and contents.—A mineral-vein may be either simple, that is, consisting entirely of one mineral, or compound, consisting of several; and may or may not be metalliferous. The minerals are usually crystalline, but layers or irregular patches of soft decomposed earth, clay, &c., frequently accompany them, especially as a layer on the wall-face (*flucan*). The non-metalliferous minerals are known as gangue or vein-stones, the more crystalline being often also popularly classed as spars. The metal-bearing minerals are known as ores. The commonest vein-stones are quartz (usually either crystalline or crypto-crystalline, with numerous fluid-inclusions), calcite, barytes, and fluorite. The presence of silica is revealed not only by the quartz, but by the hard siliceous bands so often observable along the walls of a vein. These can often be determined to be portions of the "country" which have been indurated by the deposition of silica in their pores. The ores are sometimes native metals, especially in the case of copper and gold; but for the most part are oxides, silicates, carbonates, sulphides, chlorides, or other combinations. Some of the contents of mineral-veins are associated with certain minerals more usually than with others, as galena with blende, pyrite with chalcopyrite, gold with quartz, magnetite with chlorite. Of the manner in which the contents of a mineral-vein are disposed the following are the chief varieties.

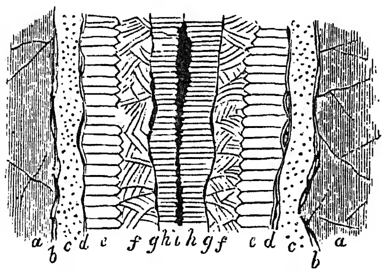

Fig. 348.—Section of Mineral-Vein with symmetrical disposition of duplicate layers.

(1) Massive.—Showing no definite arrangement of the contents. This structure is especially characteristic of veins consisting of a single mineral, as of calcite, quartz, or barytes. Some metalliferous ores (pyrites, limonite) likewise assume it.

(2) Banded, comby, in parallel (and sometimes exactly duplicated) layers or combs. In this common arrangement, each wall (*a a*, Fig. 348) may be coated with a layer of the same material, perhaps some ore or flucan (*b b*), followed on the inside by another layer (*c c*), perhaps quartz, then by layers of calcite, fluor-spar, or other veinstone, with strings or layers of ore, to the centre, where the two opposite walls may be finally united by the last zone of deposit (*i*). Even where each half of the vein is not strictly a duplicate of the other, the same parallelism of distinct layers may be traced.

(3) Brecciated, containing angular fragments of the surrounding "country," cemented in a matrix of veinstones or ores. It may often be observed that these fragments are completely enclosed within the matrix of the vein, which must have been partially open, with the matrix still in course of deposit, when they were detached from the parent rock. Large blocks (*riders*) may be thus enclosed.

(4) Drusy, containing or made up of cavities lined with crystalline minerals. The

central parts of veins frequently present this structure, particularly where the minerals have been deposited from each side towards the middle.

(5) Filamentous, having the minerals disposed in thread-like veins; this is one of the commonest structures.

Metallic ores occur under a variety of forms in mineral-veins. Sometimes they are disseminated in minute grains or fine threads (gold, pyrites), or gathered into irregular strings, branches, bunches, or leaf-like expansions (native copper), or disposed in layers alternating with the veinstones parallel with the walls of the vein (most metallic ores), or forming the whole of the vein (pyrites, and occasionally galena), or lining drusy cavities, both on a small scale and in large chambers (hæmatite, galena). Some ores are frequently found in association (galena and blende), or are noted for containing variable proportions of another metal (argentiferous galena, auriferous pyrites, titaniferous magnetite).

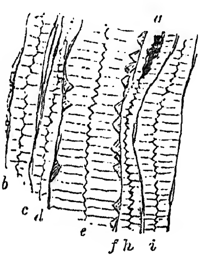

Fig. 349.—Section of Wheal Julia Lode, Cornwall showing five successive openings of the same fissure (*B.*).

a f f, Copper-pyrites and blende; *b*, *d*, *e*, *h*, *i*, quartz in crystals pointing inwards; *c*, clay; *g*, empty space.

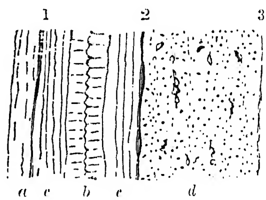

Fig. 350.—Section of part of a Lode, Godolphin Bridge, Cornwall (*B.*).

a, Quartz coating cheek of vein; *b*, quartz-crystals pointing inward; *c c*, agatiform silica; *d*, thick layer of copper-pyrites.

Successive infilling of veins.—The symmetrical disposition represented in Fig. 348 shows that the fissure remained open and had its walls coated first with the layers *b b*. Thereafter the still open, or subsequently widened, cleft received a second layer (*c c*) on each face, and so on progressively until the whole was filled up, or until only cavernous spaces (druses) lined with crystals were left. In such cases, no evidence exists of any terrestrial movement during the process of successive deposition. The fissure may have been originally as wide as the present vein, or may have been widened during the accumulation of mineral matter, so gradually and gently as not to disturb the gathering layers. But in many instances, as above stated, proofs remain of a series of disturbances whereby the formation of the vein was accelerated or interrupted. Thus at the Wheal Julia Lode, Cornwall, the central zone (*e* in Fig. 349) is formed of quartz-crystals pointing as usual from the sides towards the centre of the vein, but it is only one of five similar zones, each of which marks an opening of the fissure and the subsequent closing of it by a deposit of mineral matter along the walls.[1] The occurrence of different layers on the two walls of a vein may sometimes indicate successive openings of the fissure. In Fig. 350 the fissure at one time, no doubt,

[1] De la Beche, 'Geological Observer,' p. 698.

extended no farther than between 1 and 2. Whether the band of copper pyrites had already filled up the fissure, previous to the opening which allowed the deposit of the silica, or was introduced into a fissure opened between 2 and 3 after the deposit of the silica, is uncertain.[1]

The occurrence of rounded pebbles of slate, quartz, and granite in the lodes of Cornwall at depths of 600 feet from the surface, of gneiss in the vein at Joachimsthal at 1150 feet, and of Liassic land and freshwater shells at 270 feet in veins traversing the Carboniferous Limestone of the Mendip Hills and South Wales, seems to indicate that fissures may remain sufficiently open to allow of the introduction of water-worn stones and terrestrial organisms from the surface even down to considerable depths.[2]

Connection of veins with faults and cross-veins.—While the interspaces between any divisional planes in rocks may serve as receptacles

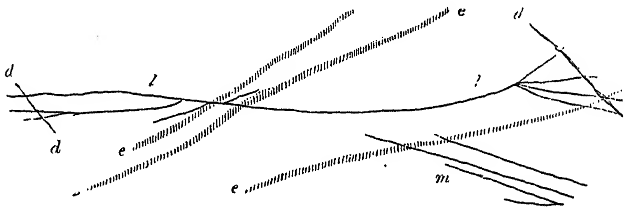

Fig. 351.—Plan of Wheal Fortune Lode, Cornwall (*B.*).
l l m, lodes of which the main one splits up towards east and west, traversing elvan dykes, *e e*, but cut by faults or cross-courses, *d d* Scale one inch to a mile.

of mineral depositions, the largest and most continuous veins have for the most part been formed in lines of fault. These may be traced, sometimes in a nearly straight course, for many miles across a country, and as far downward as mining operations have been able to descend. Sometimes veins are themselves faulted and crossed by other veins. Like ordinary faults also, they are apt to split up at their terminations. These features are well exhibited in some of the mining districts of Cornwall (Fig. 351).

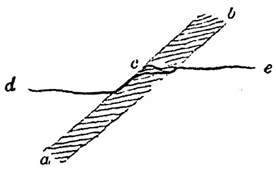

Fig. 352—Deceptive shifting of a Vein (*B.*).

The intersections of mineral-veins do not always at once betray which is the older series. If a vein has really been shifted by another, it must of course be older than the latter. But the evidence of displacement may be deceptive. In such a section as that in Fig. 352, for example, a cursory examination might suggest the inference that the vein *d e* must be later than the dyke or vein *a b*, by which its course appears to have been shifted. Should more careful scrutiny, however, lead to the detection of the vein crossing the supposed later mass at *c*, it would

[1] De la Beche, *op. cit.* p. 699.
[2] De la Beche, *op. cit.* p. 696. Moore, *Q. J. G. S.* xxiii. 483; *Brit. Assoc.* 1869, p. 360.

be clear that this inference must be incorrect.[1] In mineral districts, different series or systems of mineral-veins can generally be traced, one crossing another, belonging to different periods, and not infrequently filled with different ores and veinstones. In the south-west of England, for example, a series of fissures running N. and S., or N.N.W. and S.S.E., traverses another series, which runs in a more east and west direction (W.S.W. to E.N.E., or W.N.W. to E.S.E.). The latter (*c c*, *d d*, Fig. 353) in Cornwall contain the chief copper and tin ores, while the cross-courses (*b b*) contain lead and iron. The east and west lodes in the west part of the region were formed before those which cross them, for they are shifted, and their contents are broken through by the latter.

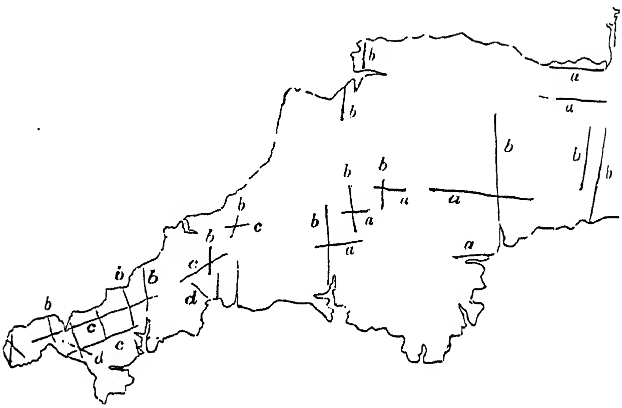

Fig. 353.—General Map of Fissures in the mineral tracts of S.W. England (*B.*).

To the east, near Exeter, the east and west faults *a a* are later than the New Red Sandstone, and in Somerset than the Lias.[2]

Relation of contents of veins to surrounding rock.—In general the deposition of metallic ores in mineral-veins has been independent of the varying petrographical nature of the country-rock.[3] Nevertheless it has long been familiar to miners that, in some regions where a vein traverses various kinds of "rocks," it may be generally richer in ore when crossing or touching some than others. In the north of England, for example, the galena is always most abundant in the limestones and scarcest in the shales, the veins in the Great Limestone (which is 150 feet thick or less) having produced as much lead as all the rest of a mass of 2000 feet of strata put together.[4] In Cornwall and Devon, it has been observed that some lodes yield tin where they

[1] De la Beche, *op. cit.* p. 657.

[2] De la Beche, *op. cit.* p. 659.

[3] Vogt, *Trans. Amer. Inst. Min. Engin.* Feb. 1901, p. 20 of reprint.

[4] The greater number and breadth of mineral veins in limestone may be due to the comparatively rapid solution of that rock by water percolating along joints or other divisional planes, with the consequent production of open chasms and chambers which would not be formed in such material as shale.

cross granite, and copper where they traverse slate; the same lode, as at Botallack, may cross three times from the one rock into the other, and each time the same change of metallic contents takes place. Some of the lodes, which are poor in ore in the slate, become rich as they cross an elvan (Fig. 354), or, on the other hand, the ore is so split up into strings in the elvan, as to be much less valuable than in the slate.

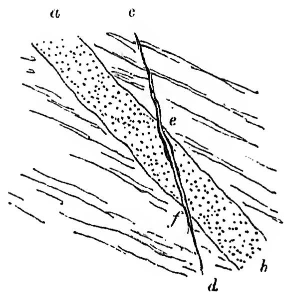

Fig. 354.—Plan of Elvan Dyke (*a b*) traversed by a metallic vein (*c e f d*), which dies out as it passes into the surrounding slate, Wheal Alfred, Guinear (*B.*)

Decomposition and recomposition in mineral-veins.—It has been noticed that the "country" through which mineral-veins run is often considerably decomposed. In Cornwall, this is specially observable in the granite. Round the Comstock Lode also, the diabase is particularly decayed. Besides the large series of complex chemical reactions brought about by the pneumatolytic vapours and solutions which, whether emanating from a magma that can now be seen in bosses of eruptive material or is still concealed within the crust, have traversed the "country" rocks,[1] extensive alterations have likewise been subsequently effected by the percolation of meteoric waters in the upper parts of the terrestrial crust. Partly to this cause is perhaps to be assigned the widespread kaolinisation of granite and of the argillaceous slates in many mining regions. The water removes most of the alkalies and alkaline earths in solution as carbonates, and some of the silica is likewise abstracted. It is common to find in mineral-veins layers of clay, earth, or other soft friable loamy substances, to which various mining names are given. The great majority of the remarkable minerals of the south-west of England occur in those parts of the lodes where such soft earths abound. These veins have evidently served as channels for the circulation of water both upward and downward, and to this circulation the decay of some bands into mere clay or earth, and the recrystallization of part of their ingredients into rare or interesting minerals, are doubtless to be ascribed. It is observable, also, that the upper parts of pyritous mineral-veins, as they approach the surface of the ground, are usually more or less decomposed from the infiltration of meteoric water, siliceous peroxide of iron and limonite being especially predominant. (Gossan of Cornwall, p. 93, Chapeau de Fer, Eiserner Hut.)

§ ii. Stocks and Stock-works. (Stöcke, Stockwerke.)

Cavernous spaces dissolved out of such rocks as limestone, or caused by rupture or otherwise, may be of indeterminate shape, and may be filled with one or more veinstones or ores, either in symmetrical zones following the outline of walls, floor, and roof, or in parallel and roughly horizontal bands (Fig. 355). Irregular metalliferous masses of this kind

[1] See Vogt, *op. cit.*, and Lindgren's paper cited *ante*, p. 812.

have long been known in Germany by the name of *Stöcke* (Stocks) when of large size, smaller aggregations being known as *Butzen* (cones) and *Nester* (tufts). The size of these indefinite accumulations of ore varies from mere nests up to masses 800 feet or more in one direction by 200 feet or more in another. Hæmatite, brown iron-ore, and galena not infrequently occur in this form in limestone, as in the "pockets" of hæmatite and "flat-works" of galena in the Carboniferous Limestone, and more notably in the ore "chambers" of the Eureka and Richmond mines of Nevada, and the Emma, Flagstaff, and other mines in Utah, from which, in recent years, such vast quantities of ore have been obtained. The "gash" or "rake" veins of galena in the north of England occur in vertical joints of limestone which have been widened by solution, and are sometimes completely cut off underneath by the floor of shale or sandstone on which the limestone lies. Lenticular aggregations of ore and

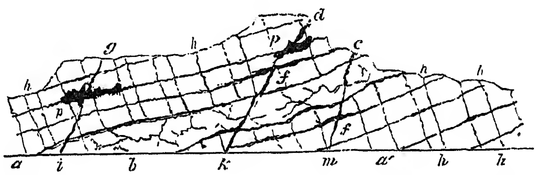

Fig. 355.—Section of Mineral deposits in limestone, Derbyshire (*B.*).
a a', Carboniferous Limestone with intercalated bed of basalt ("toadstone" *b*); *h h h h*, joints traversing the limestone; *i g*, *k d*, *m c*, veins traversing all the rocks and containing veinstones and ores; *f*, spaces between the beds enlarged by solution and filled with minerals or ores ("flat-works"); *p p*, large irregular cavernous spaces dissolved out of the rock and filled with minerals and ores.

veinstone found in granite, as in the south-west of England, are known as Carbonas; they are usually connected with true fissure-veins.

The origin of the large spaces in various kinds of rock, now filled with veinstones and ores, has been referred to solution by underground waters. In the case of limestone, the removal of the rock by descending meteoric water containing carbonic acid in solution, and the consequent production of caverns and tunnels, are familiar and easily understood. The formation of large chambers in such rocks as granite is not so intelligible. Possibly no such chambers were ever produced as empty spaces, but by a process of substitution the hot ascending solutions decomposed the silicates, preferentially in certain weak parts of the rock, and gradually replaced them with the pneumatolitic minerals and ores. Mr. Kendall has suggested such an origin even for the large hæmatitic deposits that occupy irregular cavernous spaces in the Carboniferous Limestone of the Lake District. He has pointed out as proof of substitution that the fossils of that limestone have here and there been replaced by hæmatite.[1]

Stock-works are portions of the surrounding rock or "country" so charged with veins, nests, and impregnations of ore that they can be worked as metalliferous deposits. The tin stock-works of Cornwall and

[1] *North of England Inst. Min. and Mechan. Engin.* xxviii. Part iii. and xxxi. Part v.; *Trans. Manchester Geol. Soc.* 1884.

Saxony are good examples. Sometimes a succession of such stock-works may be observed in the same mine. Among the granites, elvans, and Devonian slates of Cornwall, tin-ore has segregated in rudely parallel zones or "floors." At Botallack, at the side of ordinary tin lodes, floors of tin-ore from six to twelve feet thick and from ten to forty feet broad occur. The name of *Fahlbands* has been given to portions of "country" which have been impregnated with ores along parallel belts.

Part X. Unconformability.

Where one series of rocks, whether of aqueous or igneous origin, has been laid down continuously and without disturbance upon another series, they are said to be *conformable.* Thus in Fig. 356, the sheets of con-

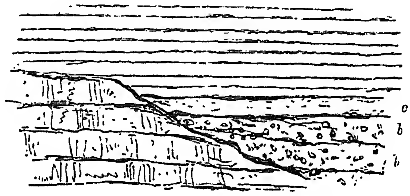

Fig. 356.—Unconformability among horizontal strata. Lias resting on Carboniferous Limestone, Glamorganshire (*B*).

glomerate (*b b*) and clay and shales (*c d*), have succeeded each other in regular order, and exhibit a perfect *conformability.* They *overlap* each other, however, each bed extending beyond the edge of that below it, and thereby indicating a gradual subsidence and enlargement of the area of deposit (p. 653). But all these conformable beds repose against an older platform *a a*, with which they have no unbroken continuity. Such a surface of junction is called an *unconformability*, and the upper are said to be *unconformable* on the lower rocks. The latter may consist of horizontal or inclined clastic strata, or contorted schists, or eruptive massive rocks. In any case, there is a complete stratigraphical break between them and the overlying formation, the beds of which rest successively on different parts of the older mass.

It is evident that this structure may occur in ordinary sedimentary, igneous, or metamorphic rocks, or between any two of these great series. It is most familiarly displayed among clastic formations, and can there be most satisfactorily studied, since the lines of bedding furnish a ready means of detecting differences of inclination and discordance of superposition. But even among igneous protrusions, and in ancient metamorphic masses, distinct evidence of unconformability is occasionally traceable. Wherever one series of rocks is found to rest upon a highly denuded surface of an older series, the junction is unconformable.[1]

[1] The occurrence of considerable contemporaneous erosion between undoubtedly conformable strata belonging to one continuous geological series has already (pp. 639-642) been described.

Hence, an uneven irregularly-worn platform below a succession of mutually conformable rocks is one of the most characteristic features of this kind of structure.

It has already been pointed out, that though conformable rocks may usually be presumed to have followed each other continuously without any great disturbance of geographical conditions, we cannot always be safe in such an inference. But an unconformability leaves no room to doubt that it marks a decided break in the continuity of deposit. Hence no kind of geological structure is of higher importance in the interpretation of the history of the stratified formations of a country. In rare cases, an unconformability may occur between two horizontal groups of strata. On the left side of Fig. 356, for instance, the beds *d* follow horizontally upon the horizontal beds (*a*). Were merely a limited section visible, disclosing only this relation of the rocks, the two groups *a* and *d* might be mistaken for conformable portions of one continuous series. Further examination, however, would lead to the detection of evidence that the limestone *a* had been upraised and unequally denuded before the deposition of the overlying strata *b c d*. This denudation would show that the apparent conformability was merely local and accidental, the older rock having really been upraised and worn down before the formation of the newer. In such a case, the upheaval must have been so uniform over some tracts as not to disturb the horizontality of the lower strata, so that the younger deposits lie in apparent conformability upon them.

As a rule, however, it seldom happens that movements of this kind have taken place over an extensive area so equably as not to produce a want of coincidence somewhere between the older and newer rocks. Most frequently, the older formations have been tilted at various angles, or even placed on end. They have likewise been irregularly and often enormously worn down. Hence instead of lying parallel, the younger beds run transgressively across the upturned denuded ends of the older. The greater the disturbance of the older rocks, the more marked is the unconformability. In Fig. 357 the lower series of beds (*c*) has been upturned and denuded before the deposition of the upper series (*a b*) upon it. In this instance, the upper worn surface of the limestone (*c*) has been perforated by boring mollusks below the sandy stratum (*b*).

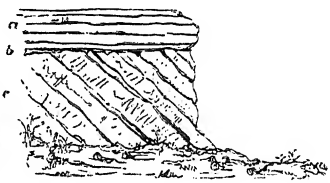

Fig. 357.—Unconformability between horizontal and inclined strata. Inferior Oolite (*a b*) resting on Carboniferous Limestone (*c*); Frome, Somerset (B.)

An unconformability forms one of the great breaks in the geological record. In Fig. 226 (p. 653), by way of illustration, we see at once that a notable hiatus in deposition, and therefore in geological chronology, must exist between the older conformable series, *a b c*, and the later strata by which these are covered. The former had been deposited, folded, upheaved, and worn down before the accumulation of the newer series upon their denuded edges. These changes must have demanded a consider-

able lapse of time. Yet, looking merely at the structure in itself, we have evidently no means of fixing, even relatively, the length of interval marked by an unconformability. By ascertaining, from some other region, the full suite of formations, we learn what members of the succession are wanting. In this way, it would be discovered that the greater part of the Carboniferous system, the whole of the Permian, and the Trias and the Lias are absent from the ground represented in Fig. 357 (compare Fig. 226). The mere violence of contrast between a set of vertical beds below and a horizontal group above, is in itself no certainly reliable criterion of the relative lapse of time between their deposition; for obviously, an older portion of a given formation might be tilted on end, and be overlain unconformably by a later part of the same formation. A set of flat rocks of high geological antiquity may, on the other hand, be conformably covered by a formation of comparatively recent date, yet, in spite of the want of discordance between the two, they might have been separated by a large portion of the total sum of geological time. Further examination will usually suffice to show that the conformability in such cases is only partial or accidental, and that localities may be found where the formations are distinctly unconformable. From the centre of the section in Fig. 358, for example, the two groups of rocks might, on casual examination, be pronounced to be conformable. Yet at short distances on either side, proofs of violent unconformability are conspicuous.

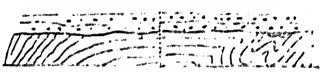

Fig. 358.—Section of local deceptive Conformability.

It sometimes happens that more than one unconformability may be detected in the same section. In Fig. 344 (p. 793), for example, the ancient gneiss at the bottom has been enormously worn down before the deposition upon it of the unconformable Torridonian conglomerates and sandstones, which in turn are unconformably overlain by the much younger Cambrian deposits. This double break in the stratigraphical sequence can be recognised even from a distance along the sides of some of the mountains in the west of Sutherland. If we pass from a single section to a wider tract of country a whole series of unconformabilities may be made out. In

Fig. 359.—Diagrammatic section to show the successive unconformabilities in the North of Scotland.

a, Lewisian gneiss; *b*, Torridonian Sandstone; *c*, Cambrian quartzite, limestone, &c.; *d*, eastern gneiss or Moine-schist (pp. 796, 892); *e*, Old Red Sandstone; *f*, Triassic and Jurassic formations; *g*, fragment of the Chalk; *h*, Tertiary lavas of the great plateaux; *i*, Boulder clay and glacial drifts lying on the denuded edges of older formations; 1, 2, 3, 4, 5, 6, 7, unconformabilities; · Thrust-plane.

the north of Scotland, at least seven such breaks in the sequence of the formations can be observed, as shown diagrammatically in Fig. 359. The two earliest of these (1 and 2 in the figure) have just been referred to, the first between the Archaean gneiss (*a*) and the Torridon sandstone (*b*), and the second between that sandstone and the Cambrian series (*c*).

The latter has had pushed over it on a great thrust-plane (p. 692) the whole vast mass of the eastern gneissose flagstones or Moine-schists. The third unconformability, representing another vast interval of time, separates the Cambrian formations and the eastern gneisses (*d*) from the Old Red conglomerate and sandstone. Still more enormous must be the fourth gap in the chronology between that sandstone and the base of the Mesozoic formations (*f*). A fifth break comes between the Jurassic series and the Cretaceous strata (*g*), for the Chalk is found to lie on the older part of that series and even on the pre-Cambrian rocks. The Cretaceous rocks have been removed by denudation from almost the whole region, save where they have been preserved under the thick cover of nearly flat unconformable older Tertiary basalts (*h* and 6), which are once more unconformably overlain by the glacial drifts (*i*, 7) and post-Tertiary and recent deposits. The relative chronological value of these several interruptions of the stratigraphical sequence is not necessarily indicated by the violence of the unconformability. It must be considered with reference to the geological age of the formations which are separated by the gap. In the following Book we shall consider how, by the evidence of organic remains, the relative importance of unconformabilities is ascertained.

Paramount though the effect of an unconformability may be in the geological structure of a country, it must nevertheless, when viewed on the large scale, be more or less local. The disturbance by which it was produced will usually be found to have affected a comparatively circumscribed region, beyond the limits of which the continuity of sedimentation may have been undisturbed. There is no satisfactory evidence of world-wide terrestrial movements by which stratigraphical breaks were produced simultaneously over the whole globe. We may, therefore, generally expect to be able to fill up the gaps in one district or country from the more complete series of geological formations of another.

BOOK V.

PALÆONTOLOGICAL GEOLOGY.

PALÆONTOLOGY treats of the structure, affinities, classification, distribution in time and genetic relations of the forms of plant and animal life imbedded in the rocks of the earth's crust.[1] Considered from the biological side, it is a part of zoology and botany. A proper knowledge of extinct organisms can only be attained by the study of living forms, while our acquaintance with the history and structure of modern organisms is amplified by the investigation of their extinct progenitors. Viewed, on the other hand, from the physical side, palæontology is a branch of geology. It is mainly in this latter aspect that it will here be discussed.

Palæontology or Palæontological Geology deals with fossils or organic remains preserved in natural deposits, and endeavours to gather from them information as to the history of the globe and its inhabitants. The term fossil, meaning literally anything "dug up," was formerly applied indiscriminately to any mineral substance taken out of the earth's crust, whether organised or not. Ordinary minerals and rocks were thus included as fossils. For many years, however, the meaning of the word has been so restricted as to include only the remains or traces of plants and animals preserved in any natural formation, whether hard rock or loose superficial deposit. The idea of antiquity or relative date is not necessarily involved in this conception of the term. Thus, the bones of a sheep buried under gravel and silt by a modern flood, and the obscure crystalline traces of a coral in ancient masses of limestone,

[1] Besides the general text-books enumerated on p. 7 the following treatises and papers on special branches or aspects of Palæontology may here be mentioned. A. Gaudry, 'Les Enchainements du monde animal dans les temps Géologiques—Mammifères Tertiaires,' Paris, 1878; 'Les Enchainements &c.—Fossiles Primaires,' 1883; 'Essai de Paléontologie Philosophique,' completing the 'Enchainements,' 1896. H. S. Williams, 'Geological Biology, an Introduction to the Geological History of Organisms,' 1895. E. C. Case, 'The Development and Geological Relations of the Vertebrates—Fishes,' *Journ. Geol.* vii. p. 393; 'Amphibia and Reptilia,' pp. 560, 622, 711; 'Birds and Mammalia,' p. 816 and vii. p. 163. C. A. White, 'The Relations of Biology to Geological Investigation'; *Nature*, lii. (1895), pp. 258, 279. H. F. Osborn, "Correlation between Tertiary Mammal Horizons of Europe and America," *Ann. New York Acad. Sci.* xiii. (1900), and other papers cited on later pages.

are equally fossils.[1] Nor has the term fossil any limitation as to organic grade. It includes not merely the remains of organisms, but also whatever was directly connected with or produced by these organisms. Thus, the resin which exuded from trees of long-perished forests is as much a fossil as any portion of the stem, leaves, flowers, or fruit, and in some respects is even more valuable to the geologist than more determinable remains of its parent trees, because it has often preserved in admirable perfection the insects which flitted about in the woodlands. The burrows or trails of a worm, in sandstone or shale, claim recognition as fossils, and indeed are commonly the only indications to be met with of the existence of annelid life among old geological formations. The droppings (coprolites) of fishes and reptiles are excellent fossils, and tell their tale as to the presence and food of vertebrate life in ancient waters. The little agglutinated cases of the caddis-worm remain as fossils in formations from which perchance most other traces of life may have passed away. Nay, the very handiwork of man, when preserved in any natural manner, is entitled to rank among fossils; as where his flint-implements have been dropped into the prehistoric gravels of river-valleys, or where his canoes have been buried in the silt of lake-bottoms.

The term fossil, moreover, suffers no restriction as to the condition or state of preservation of any organism. In some rare instances, the very flesh, skin, and hair of a mammal have been preserved for thousands of years, as in the case of mammoth carcases entombed in the frozen mud-cliffs of Siberia.[2] Generally, all or most of the original animal matter has disappeared, and the organism has been more or less completely mineralised or petrified. It often happens that the whole organism has decayed, and a mere cast in amorphous mineral matter, as sand, clay, ironstone, silica, or limestone, remains; yet all these variations must be comprised in the comprehensive term fossil.

Two preliminary questions demand attention: in the first place, how remains of plants and animals come to be entombed in rocks, and in the second, how they have been preserved there so as to be now recognisable.

§ i. **Conditions for the entombment of Organic Remains.**—If what takes place at the present day may fairly be taken as an indication of what has been the ordinary condition of things in the geological past, there must have been so many chances against the conservation of either animal or plant remains, that their occurrence among stratified formations should be regarded as exceptional, and as the result of various fortunate accidents.

1. On Land.—Let us consider, in the first place, what chances exist for the preservation of remains of the present fauna and flora of a country. The surface of the land may be densely clothed with forest, and abundantly peopled with animal life. But the trees die and moulder into soil. The animals, too, disappear, generation after generation, and leave few

[1] The word "fossil" is sometimes wrongly used as synonymous with "petrified," and we accordingly find the intolerable barbarism of "sub-fossil."

[2] For particulars of an exhumation see 'Beiträge zur Kenntniss des Russischen Reiches,' Bd. III. (1887), p. 175.

perceptible traces of their existence. If we were not aware from authentic records that Central and Northern Europe was covered with vast forests at the beginning of our era, how could we know this fact? What has become of the herds of wild oxen, the bears, wolves, and other denizens of the lowlands of primeval Europe? For unknown ages, too, the North American prairies have been roamed over by countless herds of buffaloes, yet, except here and there a skull and bones of some comparatively recent individual, every trace of these animals has disappeared from the surface.[1] How could we prove from the examination of the soil either in Europe or North America that such creatures, though now locally extinct, had once abounded there? We might search in vain for any superficial relics of them, and should learn by so doing that the law of nature is everywhere "dust to dust."

The conditions for the preservation of evidence of terrestrial (including freshwater) plant and animal life must, therefore, be always local, and, so to say, exceptional. They are supplied only where organic remains can be protected from air and superficial decay. Hence, they may be observed in lakes, peat-mosses, deltas at river-mouths, caverns, deposits of mineral-springs and around volcanoes.

a. Lakes.—Over the floor of a lake, deposits of silt, peat, marl, &c., are formed. Into these, the trunks, branches, leaves, flowers, fruits, or seeds of plants from the neighbouring land may be carried, together with the bodies of vertebrates, birds, and insects. An occasional storm may blow the lighter débris of the woodlands into the water. Such portions of the wreck as are not washed ashore again, may sink to the bottom, where they will, for the most part, probably rot away, so that, in the end, only a very small fraction of the whole vegetable matter, cast over the lake by the wind, is covered up and preserved at the bottom. In like manner, the remains of winged and four-footed animals, swept by winds or by river-floods into the lake, run so many risks of dissolution, that only a proportion of them, and probably merely a small proportion, is preserved. When we consider these chances against the conservation of the vegetable and animal life of the land, we must admit that, at the best, lake-bottoms can contain but a meagre and imperfect representation of the abundant life of the adjacent hills and plains. Lakes, however, have a distinct flora and fauna of their own. Their aquatic plants may be entombed in the gathering deposits of the bottom. Their mollusks, of characteristic types, sometimes form, by the accumulation of their remains with those of lime-secreting algæ, sheets of soft calcareous marl (pp. 605, 613), in which many of the undecayed shells are preserved. Their fishes, likewise, must no doubt often be entombed in the silt or marl.

b. Peat-mosses.—Wild animals, venturing on the more treacherous watery parts of peat-bogs, are sometimes engulphed or "laired." The antiseptic qualities of the peat preserve their remains from decay. Hence, from European peat-mosses, numerous remains of deer and oxen have been exhumed. Evidently the larger beasts of the forest ought chiefly to be looked for in these localities (p. 609).

c. Deltas at river-mouths.—It is obvious that, to some extent, both the flora and the fauna of the land may be buried among the sand and silt of deltas (p. 509). But though occasional or frequent river-floods sweep down trees, herbage, or the bodies of land-animals, the carcases so transported run every risk of having their bones separated and dispersed,[2] or of decaying or being otherwise destroyed, while still afloat; and even

[1] See Jules Marcou, 'Lettres sur les roches du Jura,' p. 103.

[2] Lower jaws, for instance, because they are among the earliest parts of the skeleton of a floating carcase to drop off, are not infrequently met with as fossils.

if they reach the bottom, they tend to dissolution there, unless speedily covered up and protected by fresh sediment. Delta-formations can therefore scarcely be expected to preserve more than a meagre outline of a varied terrestrial flora and fauna.

d. Caverns.—These are eminently adapted for the preservation of the higher forms of terrestrial life (pp. 477, 626). Most of our knowledge of the prehistoric mammalian fauna of Europe is derived from what has been disinterred from *bone-caves*. As these recesses lie, for the most part, in limestone or in calcareous rock, their floors are commonly coated with stalagmite from the drip of the roof; and as this deposit is of great closeness and durability, it has effectually preserved whatever it has covered or enveloped. The caves have, in many instances, served as dens for predatory beasts, like the hyæna, cave-lion, and cave-bear, which sometimes dragged their prey into these recesses. In other cases, they have been merely holes whither different animals crawled to die, or into which they fell or were swept by inundations. Under whatever circumstances the animals left their remains in these subterranean retreats, the bones have been covered up and preserved. Still we must admit that, after all, only a small fraction of the animals of the time would be included, and therefore that the evidence of the cavern-deposits, profoundly interesting and valuable as it is, presents us with merely a glimpse of one aspect of the life of the land.

e. Deposits of mineral-springs.—The deposits of mineral matter, resulting from the evaporation of the water of mineral springs on the surface of the ground, serve as receptacles for occasional leaves, land-shells, insects, dead birds, small mammals, and other remains of the plant and animal life of the land (pp. 475, 611).

f. Volcanic deposits.—Sheets of lava and showers of volcanic dust may entomb terrestrial organisms (pp. 276, 755). It is obvious, however, that even over the areas wherein volcanoes occur and continue active, they can only to a very limited extent entomb and preserve the flora and fauna of the land.

2. In the Sea.—In the next place, if we turn to the sea, we find certainly more favourable conditions for the preservation of organic forms, but also many circumstances which operate against it.[1]

a. Littoral deposits.—While the level of the land remains stationary, there can be but little effective entombment of marine organisms in littoral deposits; for only a limited accumulation of sediment will be formed until subsidence of the sea-floor takes place. In the trifling beds of sand or gravel thrown up by storms above the limits of ordinary wave-action on a stationary shore, only the harder and more durable forms of life, such as the stronger gasteropods and lamellibranchs, which can withstand the triturating effects of the beach-waves, are likely to remain uneffaced (p. 580).

b. Deeper-water terrigenous deposits.—Below tide-marks, along the margin of land whence sediment is derived, conditions are more favourable for the preservation of marine organisms. Sheets of sand and mud are there laid down, wherein the harder parts of many forms of life may be entombed and protected from decay (p. 581). But probably

[1] Reference may be made here to some terms which in recent years have come into general use in reference to the fauna of the ocean. "Plankton," proposed by Hensen in 1887 to denote all animals living passively in the sea, was subsequently enlarged in meaning by Haeckel so as to embrace all the fauna of the oceanic waters. "Benthos" is applied to all plants and animals living on or creeping over the sea-floor. "Nekton" embraces all the free-swimming forms, such as fishes and marine mammalia. An animal or plant may at different periods of its existence pass from one of these designations to another, as where it begins in the benthos and ends in the nekton, or *vice versa*. The student will find a suggestive essay on the application of modern views regarding the habitats of marine animals to fossil forms in Prof. J. Walther's paper, "Ueber die Lebensweise fossiler Meeresthiere," *Z. D. G. G.* xlix. (1897), pp. 211-273. The sections on the mode of life of Graptolites and on the habits and transport of Ammonites are of special interest.

only a small proportion of the fauna that crowds these marginal waters of the ocean, with occasional pelagic species, may be expected to occur in such deposits. Moreover, for the entombment and preservation of the remains of these organisms, there must obviously be a sufficiently abundant and rapid deposit of sediment, and for the preservation of a continuous and prolonged record of the submarine life, there must likewise be a slow depression of the sea-bottom. Under the most favourable conditions, therefore, the organic remains actually preserved will usually represent little more than a mere fraction of the whole assemblage of life in these juxta-terrestrial parts of the ocean.

c. Abysmal deposits.—In proportion to distance from land, the rate of deposition of sediment on the sea-floor must become feebler, until in the remote central abysses it reaches a hardly appreciable minimum, while at the same time, the solution of calcareous organisms may become marked in deep water (pp. 566, 621). Except, therefore, where organic deposits such as ooze are forming in these more pelagic regions, the conditions must be on the whole unfavourable for the preservation of any adequate representation of the deep-sea fauna. Hard enduring objects, such as teeth and bones, may slowly accumulate and be protected by a coating of peroxide of manganese, or of silicates, such as are now forming here and there over the deep sea-bottom. Yet a deposit of this nature, if raised into land, would supply but a meagre picture of the life of the sea.

In considering the various conditions under which marine organisms may be entombed and preserved, we must take into account certain occasional phenomena, when sudden, or at least rapid and extensive, destruction of the fauna of the sea may be caused. (1) Earthquake shocks have been followed by the washing ashore of vast quantities of dead fish (*ante*, p. 375). (2) Violent storms, by driving shoals of fishes into shallow water and against rocks, produce enormous destruction. Dr. Leith Adams describes the coast of part of the Bay of Fundy as being covered to a depth of a foot in some places with dead fish, dashed ashore by a storm on the 24th of September, 1867.[1] (3) Copious discharges of fresh water into the sea have been observed to cause extensive mortality among marine organisms. Thus, during the S.W. monsoon and accompanying heavy rains, the west coasts of some parts of India are covered with dead fish thrown ashore from the sea.[2] (4) A sudden irruption of the outer sea into a sheltered and partially brackish inlet may cause the extinction of many of the denizens of the latter, though a few may be able to survive the altered conditions.[3] (5) Volcanic explosions have been observed to cause considerable destruction to marine life, either from the heat of the lava, or from the abundance of ashes or of poisonous gases. (6) Want of oxygen, when fishes are crowded together in frightened shoals, or when, burrowing in sand and mud, they are overwhelmed with rapidly accumulating detritus, is another cause of mortality.[4] (7) Shoals of fish are sometimes driven ashore by the large predatory denizens of the deep, such as whales and porpoises. (8) Too much or too little heat in shallow water leads to the destruction of fish. Large numbers of salmon are sometimes killed in the pools of a river during dry and hot weather. (9) Considerable mortality occasionally arises along the littoral zone from the effects of severe frost. (10) Various diseases and parasites affect fish, and lead directly to their death, or weaken them so that they are more easily caught by their enemies.[5] Such phenomena as those here enumerated suggest probable causes of death in the case of fossil fishes, whose remains are sometimes crowded together in various geological formations, as for example, in the Old Red Sandstone.

Of the whole sea-floor, the areas best adapted for preserving organic

[1] *Q. J. G. S.* xxix. p. 303.

[2] Denison, *op. cit.* xviii. p. 453. *Nature* (19th December 1872, p. 124) gives another instance.

[3] Forchhammer, *Edin. New. Phil. Journ.* xxxi. p. 69. *Nature*, i. p. 151; xiii. p. 107.

[4] Sir J. W. Dawson, *Geologist*, ii. (1859), p. 216.

[5] For fuller references, see an interesting paper by Professor T. Rupert Jones, *Geol. Mag.* 1882, p. 533.

exuviæ are obviously (1) that juxta-terrestrial belt in which life is most varied and abundant, and where sediment, transported by rivers and currents from the adjacent shores, is chiefly laid down; and (2) those tracts of the open ocean where the bottom rises near enough the surface to become the home of an abundant and varied fauna and the site of thick deposits of organic remains, as on the tops of submarine volcanic ridges. The most favourable conditions for the accumulation of a thick mass of marine fossiliferous strata will arise when the area of deposit is undergoing a gradual subsidence. If the rate of depression and that of deposit be equal, or nearly so, the movement may conceivably continue for a vast period without producing any great apparent change in marine geography, and even without seriously affecting the distribution of life over the sea-floor within the area of subsidence. Hundreds or thousands of feet of sedimentary strata may conceivably be in this way heaped up round the continents, containing a fragmentary series of remains, chiefly forms of shallow-water life which had hard parts capable of preservation.

There can be little doubt that such has, in fact, been the history of the main mass of stratified formations in the earth's crust. These piles of marine strata have unquestionably been laid down for the most part in comparatively shallow water, within the area of deposit of terrestrial sediment. Their great depth seems only explicable by prolonged and repeated movements of subsidence, sometimes interrupted, however, as we know, by other movements of a contrary kind. These geographical changes affected at once the deposition of inorganic materials and the succession of organic forms. One series of strata is sometimes abruptly succeeded by another of a very different character, and we not uncommonly find a corresponding contrast between their respective organic contents.

It follows, from these conditions of sedimentation, that representatives of the abysmal deposits of the central oceans are not likely to be met with among the geological formations of past times. Thanks to the great work done by the *Challenger* and other national expeditions, we have learnt what are the leading characters of the accumulations now forming on the deeper parts of the ocean-floor. So far as we yet know, they have no analogues among the formations of the earth's crust. They differ, indeed, so entirely from any formation which geologists have considered to be of deep-water origin as to indicate that, from early geological times, the present great areas of land and sea have remained on the whole where they are, and that the land consists mainly of strata formed of terrestrial débris laid down at successive epochs in the surrounding comparatively shallow seas.

§ ii. **Preservation of Organic Remains in mineral masses.**—The condition of the remains of plants and animals in rock-formations depends, first, upon the original structure and composition of the organisms, and secondly, upon the manner in which their "fossilisation," that is, their entombment and preservation, has been effected.

1. Influence of original structure and composition.—The durability of organisms is determined by their composition and structure.

The internal skeletons of most vertebrate animals consist mainly of phosphate of lime; in many saurians and fishes there is also an exo-skeleton of hard bony plates or of scales. It is these durable portions that remain as evidence of the former existence of vertebrate life. The hard parts of invertebrates present a greater variety of composition. In the vast majority of cases, they consist of calcareous matter, either calcite or aragonite. The carbonate of lime is occasionally strengthened by phosphate, while in a few cases, as in the horny brachiopods, in *Conularia*, *Serpula*, and some other forms, the phosphate is the chief constituent.[1] Next in abundance to lime is silica, which constitutes the frustules of diatoms and the harder parts of many protozoa, and is found also in the teeth of some mollusks. The integuments of insects, the carapaces of crustacea, and some other organisms, are composed fundamentally of chitin,[2] a transparent horny substance which can long resist decomposition. In the vegetable kingdom, the substance known as cellulose forms the essential part of the framework of plants. In dry air, it possesses considerable durability, also when thoroughly water-logged and excluded from meteoric influences. In the latter condition, imbedded amid mud or sand, it may last until gradually petrified.[3]

It is a familiar fact that in the same stratum different organisms occur in remarkably different states of conservation. This is sometimes strikingly exemplified among the mollusca. The conditions for their preservation may have been the same, yet some kinds of shells are found only as empty moulds or casts, while others still retain their form, composition, and structure. This discrepancy no doubt, points to original differences of composition or structure. The aragonite shells of a stratum may be entirely dissolved, while those of calcite may remain.[4] The presence, therefore, of calcite forms only does not necessarily imply that others of aragonite were not originally present. But the conditions of petrifaction have likewise greatly varied. In the clays of the Mesozoic formations, for example, cephalopods may be exhumed retaining even their pearly nacre, while in corresponding deposits among the Palæozoic systems they are merely crystalline calcite casts.

2. Fossilisation.—The condition in which organic remains have been entombed and mineralised may be reduced to three leading types.

(1) *The original substance is partly or wholly preserved.*—Several grades may be noticed: (*a*) where the entire animal substance is retained, as in the frozen carcases of mammoths in the Siberian cliffs; (*b*) where the organism has been mummified by being encased in resin or gum (insects in amber); (*c*) where the organism has been carbonised with or without retention of its structure, as is characteristically shown in peat, lignite, and coal; (*d*) where a variable portion of the original substance, and especially the organic matter, has been removed, as happens with shells and bones: this is no doubt one of the first steps towards petrifaction.

(2) *The original substance is entirely removed, with retention merely of external form.*—Mineral matter gathers round the organism and hardens there, while the organism itself decays. Eventually a mere mould of the plant or animal is left in stone. Every stage in this process may be studied along the margin of calcareous springs and streams (*ante*, p. 611). The lime in solution is precipitated round fibres of moss, leaves, twigs, &c., which are thereby incrusted with mineral matter. While the crust thickens, the organism inside decays, until a mere hollow mould of its form remains. Among

[1] Logan and Hunt, *Amer. Journ. Sci.* xvii. (1854), p. 235.

[2] According to C. Schmidt, the composition of this substance is C, 46·64; H, 6·60; N, 6·66; O, 40·20. The brown chitin of Scottish Carboniferous scorpions is hardly distinguishable from that of recent species.

[3] On cellulose and coal, see C. F. Cross and E. J. Bevan, *Brit. Assoc.* 1881, Sects. p. 603.

[4] See *ante*, pp. 155, 177, 613, and authorities there cited.

stratified rocks, moulds of organic forms are of frequent occurrence. They may be filled up with mineral matter, washed in mechanically or deposited as a chemical precipitate, so that a cast in stone replaces the original organism. Such casts are particularly common in sandstone, which, being a porous rock, has allowed water to filter through it and remove the substance of enclosed plant-stems, shells, &c. In the sandstones of the Carboniferous system, casts in compacted sand of stems of *Lepidodendron* and other plants are abundant. Some of the most remarkable examples of this type of fossilisation are the Jelly-fishes which have left their records in Cambrian and Jurassic strata. These animals had no hard parts; like their modern representatives, they were mere gelatinous structures full of water, yet they have left their clear impressions on the fine silt in which they were entombed.[1] It is obvious that in casts of this kind, no trace remains of the original structure of the organism, but merely of its external form.

(3) *The original substance is molecularly replaced by mineral matter, with partial or entire preservation of the internal structure of the organism.*—This is the only true **petrifaction.** The process consists in the abstraction of the organic substances, molecule by molecule, and in their replacement by precipitated mineral matter. So gradual and thorough has this interchange often been, that the minutest structures of plant and animal have been perfectly preserved. Silicified wood is a familiar example (see p. 474).

The chief substance which has replaced organic forms in rocks is calcite, either crystalline or in an amorphous granular condition. In assuming a crystalline (or fibrous) form, this mineral has often observed a symmetrical grouping of its component individuals, these being usually placed with their long axes perpendicular to the surface of an organism. In many cases, among invertebrate remains, the calcite now visible is pseudomorphous after aragonite (p. 107). Next in abundance as a petrifying medium is **silica**, most commonly in the chalcedonic form, but also as quartz. It is specially frequent in some limestones, as chert and flint, replacing the carbonate of lime in mollusks, echinoderms, corals, &c. It also occurs in irregular aggregates, in which organisms are sometimes beautifully preserved. It forms a frequent material for the petrifaction of fossil wood. Silicification, or the replacement of organisms by silica, is the process by which minute organic structures have been most perfectly preserved. In a microscopic section of silicified wood, the organisation of the original plant may be as distinct as in the section of any modern tree.[2] **Pyrites** and **marcasite**, especially the latter, are common replacing minerals, abundant in argillaceous deposits, as, for example, among the Jurassic and Cretaceous clays. **Siderite** has played a similar part among the ironstones of the Coal-measures, where shells and plants have been replaced by it. Many other minerals are occasionally found to have been substituted for the original substance of organic remains. Among these may be mentioned glauconite (replacing or filling foraminifera, p. 627), vivianite (specially frequent as a coating on the weathered surface of scales and bones), barytes, celestine, gypsum, talc, lead-sulphate, carbonate, and sulphide; copper-sulphide and native copper; hæmatite and limonite; zinc-carbonate and sulphide; cinnabar; silver chloride and native silver; sulphur, fluorite, phosphorite.[3]

§ iii. **Relative Palæontological value of Organic Remains.**—As the conditions for the preservation of organic remains exist more favourably under the sea than on land, relics of marine must be far more abundantly conserved than those of terrestrial organisms. This is true to-day, and has doubtless been true in all past geological time. Hence, for the purposes of the geologist, fossil remains of marine forms of life far sur-

[1] C. D. Walcott, 'Fossil Medusæ,' Monograph xxx. *U. S. G. S.* (1898).

[2] On the process of petrifaction in fossil plants, see J. Felix, *Z. D. G. G.* xlix. (1897), p. 182.

[3] Roth, 'Chem. Geol.' i. p. 605. Jannettaz, *Bull. Soc. Géol. France* (3), vii. p. 102.

pass all others in value. Among them, there will necessarily be gradations in importance, regulated chiefly by their possession of hard parts, readily susceptible of preservation among marine deposits. Among the Protozoa, foraminifers, radiolarians, and sponges, possessing siliceous or calcareous organisations, have been preserved in deposits of all ages. Of the Cœlenterates, those which, like the corals, secrete a calcareous skeleton are important rock-builders. The Echinoderms have been so abundantly preserved that their geological history and development are better known than those of most other classes of invertebrates. The Annelids, on the other hand (except where they have been tubicolar), have almost entirely disappeared, though their former presence is often revealed by the trails they have left upon surfaces of sand and mud. Of all the marine tribes which live within the juxta-terrestrial belt of sedimentation, unquestionably the Mollusca stand in the front rank, as regards their aptitude for becoming fossils. In the first place, they almost all possess a hard durable shell, composed chiefly of mineral matter, capable of resisting considerable abrasion, and readily passing into a mineralised condition. In the next place, they are extremely abundant both as to individuals and genera. They occur on the shore up to high-water mark, and range thence down into the abysses. Moreover, they appear to have possessed these qualifications from early geological times. In the marine Mollusca, therefore, we have a common ground of comparison between the stratified formations of different periods. They have been styled the alphabet of palaeontological inquiry. It will be seen, as we proceed, how much, in the interpretation of geological history, depends upon the testimony of sea-shells.

Turning next to the organisms of the land, we perceive that the abundant terrestrial flora has a comparatively small chance of being well represented in a fossil state; that indeed, as a rule, only that portion of it of which the leaves, twigs, flowers, fruits, or trunks are blown into lakes, or swept down by rivers, is likely to be partially preserved. Terrestrial plants, therefore, occur in comparative rarity among stratified rocks, and furnish in consequence only limited means of comparison between the formations of different ages and countries, although where they have been plentifully preserved they furnish valuable bases for stratigraphical correlation, as has been shown during recent years in the case of the Carboniferous and Cretaceous floras (see Book VI. Part II. sect. iv. § 1; Part III. sect. iii. § 1). Of land animals, the vast majority perish, and leave no permanent trace of their existence. Predatory and other forms, whose remains may be looked for in caverns or peat-mosses, must occur more numerously in the fossil state than birds, and are correspondingly more valuable to the geologist for the comparison of different strata.

Another character determines the relative importance of fossils as geological monuments. All organisms have not the same inherent capability of persistence. The longevity of an organic type has, on the whole, been in inverse proportion to its perfection. The more complex its structure, the more susceptible has it been of change, and consequently the less likely to be able to remain unaffected by the influences of vary

ing climate, and other physical conditions. A living species of foraminifer or brachiopod, endowed with comparative indifference to its environment, may spread over a vast area of the sea-floor, and the same want of sensibility enables it to endure through the changing physical conditions of successive geological periods. It may thus possess a great range, both in space and time. But a highly-specialised mammal is usually confined to but a limited extent of country, and to a narrow chronological range.[1]

§ **iv. Uses of Fossils in Geology.**—Apart from their profound interest as records of the progress of organised being upon the earth, fossils serve three main purposes in geological research: (1) to throw light upon former conditions of physical geography, such as the presence of land, rivers, lakes, and seas, in places where they do not now exist, upon changes of climate, and upon the former distribution of plants and animals; (2) to furnish a guide in geological chronology whereby rocks may be classified according to relative date, and the facts of geological history may be arranged and interpreted as a connected record of the earth's progress; and (3) to afford a clue to the causes which have led to the distribution of animals over the globe in ancient and modern time.

1. Changes in Physical Geography.—A few examples will suffice to show the manifold assistance which fossils furnish to the geologist in the elucidation of ancient geography.

(*a*) Former land-surfaces are revealed by the presence of tree-stumps in their positions of growth, with their roots branching freely in the underlying stratum, which, representing the ancient soil, often contains leaves, fruits, and other sylvan remains, together with traces of the bones of land-animals, remains of insects, land-shells, &c. Ancient woodland surfaces of this kind, found between tide-marks, and even below low-water line, round different parts of the British coast, have been above described as "Submerged Forests" (p. 388). Of more ancient date are the "dirt-beds" of Portland (Book VI. Part III. Sect. ii. § 2), which, by their layers of soil and tree-stumps, show that woodlands of cycads sprang up over an upraised sea-bottom and were buried beneath the silt of a river or lake. Still farther back in geological history come the coal-growths of the Carboniferous period, which, with their "under-clays" or soils, point to wide jungles of terrestrial or aquatic plants, like the modern mangrove-swamps, that were successively submerged and covered with sand or silt (Book VI. Part II. Sect. iv. § 1).

(*b*) The former existence of lakes can be satisfactorily proved from beds of marl or lacustrine limestone full of freshwater shells, or from fine silt with leaves, fruits, and insect remains. Such deposits are growing abundantly at the present day, and they occur on various horizons among the geological formations of past times. The well-known Nagelflue of Switzerland and the caddis-worm limestones of Auvergne can be shown from their fossil contents to be essentially lacustrine deposits (Book VI. Part IV. Sect. ii. § 2). Still more important are the ancient Eocene and Miocene lake-formations of North America, whence so rich a terrestrial and lacustrine flora and fauna have been obtained (Book VI. Part IV. Sect. i. § 1).

[1] The great value of mammalian remains for purposes of geological chronology has been well enforced by Professor Marsh, Address to the American Association for the Advancement of Science, 30th August 1877, *Amer. Journ. Sci.* xiv. (1877), pp. 338-378; xlii. (1891), p. 336; vi. (1898), p. 483; *Geol. Mag.* 1898, p. 565. Dr. W. T. Blanford points out that, in some cases at least, fluviatile mollusks have been more short-lived than terrestrial mammals, Address, *Geol. Section, Brit. Assoc.* 1884.

(*c*) Old sea-bottoms are vividly brought before us by beds of marine shells and other organisms. Layers of water-worn gravel and sand, with rolled shells of littoral and infra-littoral species, unmistakably mark the position of a former shore-line. Deeper water is indicated by finer muddy sediment, with relics of the fauna that prevails beneath the reach of waves and ground-swell. Limestones full of corals, or made up of crinoids, point to the slow, continuous growth and decay of generation after generation of organisms in clear sea-water.

(*d*) Variations in the nature of the water, or of the sea-bottom, may sometimes be shown by changes in the size or shape of the organic remains. If, for example, the fossils in the central and lower parts of a limestone are large and well-formed, but in the upper layers become dwarfed and distorted, we may reasonably infer that the conditions for their continued existence at the locality must have been gradually impaired. The final complete cessation of these favourable conditions is shown by the replacement of limestone by shale, indicative of the water having become muddy, and by the disappearance of the organisms, which had shown their sensitiveness to the change (pp. 756, 757).

(*e*) The proximity of land at the time when a fossiliferous stratum was in the course of accumulation may be sufficiently proved by mere lithological characters, as has been already explained; but the conclusion may be further strengthened by the occurrence of leaves, stems, and other fragments of terrestrial vegetation, with remains of insects, birds, or terrestrial mammals, which, if found in some numbers in certain strata intercalated among others containing marine organisms, would make it improbable that they had been drifted far from land (p. 583).

(*f*) The existence of different conditions of climate in former geological periods is satisfactorily demonstrated from the testimony of fossils. Thus, an assemblage of the remains of palms, gourds, and melons, with bones of crocodiles, turtles, and sea-snakes, proves a sub-tropical climate to have prevailed over the south of England in the older Tertiary ages (Book VI. Part IV. Sect. i. § 1). On the other hand, the extension of a cold or arctic climate far south into Europe during post-Tertiary time, can be shown from the existence of remains of arctic animals, even in the south of England and of France (Book VI. Part V.). This is a use of fossils, however, where great caution must be observed. We cannot affirm that, because a certain species of a genus lives now in a warm part of the globe, every species of that genus must always have lived in similar circumstances. The well-known examples of the mammoth and woolly rhinoceros that lived in the cold north, while their modern representatives inhabit some of the warmest regions of the globe, may be usefully remembered as a warning against any such conclusion. When, however, not one fossil merely, but the whole assemblage of fossils in a group of rocks, finds its modern analogy in a certain general condition of climate, we may, at least tentatively, infer that the same kind of climate prevailed where that assemblage lived. Such an inference would become more and more unsafe in proportion to the antiquity of the fossils, and their divergence from existing forms.[1]

As an illustration of the application of the evidence of fossils in the interpretation of ancient conditions of geography at different geological periods, reference may be made

[1] See Neumayr, *Nature*, xlii. (1890), pp. 148, 175. This author specially devoted himself to the study of ancient climates as indicated by fossils. As an illustration of his methods his essay on the climatic zones of Jurassic and Cretaceous time may be cited, *Denksch. Akad. Wien*, xlvii. (1883), and l. (1885). On fossil plants in relation to climate see J. D. Hooker, Address, *Brit. Ass.* (1881), p. 727; *Proc. Roy. Soc.* xxvi. (1877), p. 441; A. C. Seward, "Fossil plants as tests of Climate"—the Sedgwick Prize Essay for 1892; and the elaborate essay by Max Semper, "Das Paläothermale Problem, speciell die klimatischen Verhältnisse des Eocän in Europa und im Polargebiet," *Z. D. G. G.* xlviii. (1896), pp. 261-349, li. (1899), pp. 185-206. Probably a wider and more precise and critical collation of the palæontological evidence is needed before satisfactory conclusions can be drawn from it.

more especially to the investigation of the various basins in which the Jurassic rocks of Europe were deposited. The positions of the seas and lands, and the variations of climate have been ascertained with sufficient definiteness to give us some conception of the physical geography of that part of the globe during early Mesozoic time.[1]

2. Geological Chronology.—Although absolute dates cannot be fixed in geological chronology, it is not difficult to determine the relative age of different strata. For this purpose the fundamental law is based on the "order of superposition" (pp. 657, 855): in a series of stratified formations, the older underlie the younger. It is not needful that we should actually see the one lying below the other. If a continuous conformable succession of strata dips steadily in one direction, we know that those at the one end must underlie those at the other, because we can trace the whole series between them. Rare instances occur, where strata have been so folded by great terrestrial disturbance that the younger are made to underlie the older. But this inversion can usually be made clear from other evidence. The true order of superposition is decisive of the relative ages of stratified rocks.

The order of sequence having been determined, it is needful to find some means of identifying a particular formation elsewhere, when its stratigraphical relations may possibly not be visible. At first, it might be thought that the mere external aspect and mineral characters of the rocks ought to be sufficient for this purpose. Undoubtedly these features may suffice within the same limited region in which the order of sequence has already been determined. But as we recede from that region, they become more and more unreliable. That this must be the case will readily appear, if we reflect upon the conditions under which sedimentary accumulations have been formed. The markedly lenticular nature of these deposits has already been described (p. 651). At the present day, the sea-bottom presents here a bank of gravel, there a sheet of sand, elsewhere layers of mud, or of shells, or of organic ooze, all of which are in course of deposit simultaneously, and will as a rule be found to shade off laterally into each other. The same diversity of contemporaneous deposits has obtained from the earliest geological periods. Conglomerates, sandstones, shales, and limestones occur on all geological horizons, and replace each other even on the same platform. The Coal-measures of Pennsylvania are represented west of the Rocky Mountains by thousands of feet of massive marine limestones. The white Chalk of England lies on the same geological horizon with marls and clays in North Germany, with thick sandstones in Saxony, with massive limestones in the south of France. Mere mineral characters are thus quite unreliable, save within comparatively restricted areas.

The solution of this problem was found, and was worked out for the Secondary rocks of England, by William Smith at the end of the eighteenth century. It is supplied by organic remains, and depends upon the law that the order of succession of plants and animals has been similar all over the world. According to the order of superposition, the

[1] See especially Neumayr, *Verh. Geol. Reichsanst.* 1871, p. 54, *Jahrb. Geol. Reichsanst.* xxviii. (1878), and his essay cited in the foregoing note.

fossils found in any deposit must be older than those in the deposit above, and younger than those in that below. This order, however, must be first accurately determined by a study of the actual stratigraphy of the formations; for, so far as regards organic structure or affinities, there may be no discoverable reason why a particular species should precede or follow another. Unless, for example, we knew from observation that *Rhynchonella pleurodon* is a shell of the Carboniferous Limestone, and *Rhynchonella tetrahedra* is a shell of the Lias, we could not, from mere inspection of the fossils themselves, pronounce as to their real geological position.[1] It is quite true that, by practice, a palæontologist has his eye so trained that he can make shrewd inferences as to the phyllogeny of extinct forms and as to the actual horizon of fossils which he may never have seen before (and this is more especially true in regard to the mammalia, as will be immediately adverted to), but to do this he should possess a wide experience of the ascertained order of appearance of fossils, as determined by the law of superposition. For geological purposes, therefore, and, indeed, for all purposes of comparison between the faunas and floras of different periods, it is absolutely essential, first of all, to have the order of superposition of strata rigorously determined. Unless this is done, the most fatal mistakes may be made in palæontological chronology. But when it has once been done in one typical district, the order thus established may be held as proved for a wide region where, from paucity of sections, or from geological disturbance, the true succession of formations cannot be satisfactorily determined.

The order of superposition having been determined in a great series of stratified formations, it is found that the fossils at the bottom are not quite the same as those at the top of the series. As we trace the formations upward, we discover that species after species of the lowest platforms disappears, until perhaps not one of them is found. With the cessation of these older species, others make their entrance. These, in turn, are found to die out and to be replaced by newer forms. After patient examination of the rocks, it is ascertained that every well-marked formation is distinguishable by its own species or genera (characteristic fossils, Leitfossilien) or by a general assemblage or *facies* of organic forms. This can only, of course, be determined by actual practical experience over an area of some size. The characteristic fossils are not always the most numerous; they are those which occur most constantly and have not been observed to extend their range above or below a definite geological horizon or platform. For the determination of geological chronology, as already pointed out, it may be affirmed as a general principle that the higher and more specialised the type of organism the more local is its area in space and the more limited its range in time. Hence mammalian remains

[1] The derivation of some forms by descent from others may be inferred with more or less probability, and such genetic affinities may furnish valuable suggestions to the palæontologist. But that the risk of erroneous interpretation and fanciful deduction in such matters is real and serious was well shown in the discussion of the presumed derivation of the Olenellidian trilobites from the Paradoxidian forms, until it was shown that the former were really the precursors of the latter.

have a special value in this respect.[1] But some invertebrate groups possess great importance as fixing stratigraphical horizons; as, for example, the ammonites in the Jurassic and the graptolites in the Silurian system.

As illustrations of fossils characteristic of some of the larger subdivisions of the Geological Record, the following may be given. Lepidodendra and Sigillariæ are typical of Old Red Sandstone and Carboniferous deposits; Graptolites of the Silurian system; Trilobites of Palæozoic rocks from Cambrian to Permian, but more particularly of the Cambrian and Silurian systems; Cystideans of the older Palæozoic, especially the Silurian, rock-groups; Blastoids pre-eminently of Lower Carboniferous rocks. Orthoceratites are mainly Palæozoic, and Ammonites Mesozoic; Ichthyosaurs and Plesiosaurs, Mesozoic; Nummulites, Palæotherium, Anoplotherium, Hyopotamus, and Anthracotherium belong to older Tertiary, and Mastodon, Elephas, Hyæna, Cervus, and Equus to younger Tertiary and recent time. The occurrence of such organisms in any rock, at once indicates the great division of geological time to which the rock should be assigned.

The distinctive fossils of a system or formation, having been ascertained from a sufficiently prolonged and extended experience, serve to identify that series of rocks in its progress across a country. Thus, as we trace a formation into tracts where it would be impossible to determine the true order of superposition, owing to the want of sections, or to the disturbed condition of the rocks, we can employ the typical fossils as a means of identification, and speak with confidence as to the succession of the rocks. We may even demonstrate that in some mountainous ground, the strata have been turned completely upside down, if we can show that the fossils in what are now the uppermost layers ought properly to lie underneath those in the beds below them.

Prolonged study of the succession of organic types in the geological past all over the world, has given palæontologists some confidence in fixing the relative age of fossils belonging even to previously unknown species or genera, and occurring under circumstances where no order of superposition has been made out. For instance, the general sequence of mammalian types having now been settled by the law of superposition, the horizon of a mammaliferous deposit may be approximately determined by the grade or degree of evolution denoted by its mammalian fossils. Thus, should remains be generically abundant, differing from those now living, and presenting none of the extreme contrasts which are now found among our higher animals, should they embrace neither true ruminants, nor solipedes, nor proboscidians, nor apes, they might with high probability be referred to the Eocene period.[2] Reasoning of this kind must be based, however, upon a wide basis of evidence, seeing that the progress of development has been far from equal in all ranks of the animal world.

[1] Consult the papers of Professor Marsh quoted on p. [illegible], and see especially the plate in the 1891 paper, in which the successive mammalian zones in the Geological Record of North America are given; also the papers of Prof. Osborn, Dr. Wortman, and Mr. W. D. Matthew on the Tertiary lake-basins of western North America and their vertebrate faunas, especially the essay, "A Provisional Classification of the Fresh-water Tertiary of the West," *Bull. Amer. Mus. Nat. Hist.*, New York, xii. 1899, p. 19.

[2] Gaudry, 'Les Enchaînements du Monde Animal,' 1878, p. 216.

Observations made over a large part of the surface of the globe have enabled geologists to divide the stratified part of the earth's crust into systems, formations, and groups (p. 860). These subdivisions are frequently marked off from each other by lithological characters. But, as already remarked, mere lithological differences afford at the best but a limited and local ground of separation. Two masses of sandstone, for example, having exactly the same general external and internal characters, may belong to very different geological periods. On the other hand, a series of limestones in one locality may be the exact chronological equivalent of a set of sandstones and conglomerates at another, and of a series of shales and clays at a third.

Some clue is accordingly needed, which will permit the divisions of the stratified rocks to be grouped and compared chronologically. This fortunately is well supplied by their characteristic fossils. Each formation being distinguished by its own assemblage of organic remains, it can be followed and recognised even amid the crumplings and dislocations of a disturbed region. The same general succession of organic types has been observed over a large part of the world, though, of course, with important modifications in different countries.

It is evident that, in this way, a method of comparison is furnished whereby the stratified groups of different parts of the earth's crust can be brought into relation with each other. We find, for example, that a certain group of strata is characterised in Britain by certain genera and species of corals, brachiopods, lamellibranchs, gasteropods, and cephalopods. A group of rocks in Bohemia, differing more or less from the British type in lithological aspect, contains on the whole the same genera, and some even of the some species. In Scandinavia, a set of beds may be seen, unlike perhaps in external characters to the British type, but yielding many of the same fossils. In Canada and parts of the northern United States, other rocks enclose some of the same, and of closely allied genera and species. All these groups of strata, having the same general facies of organic remains, are regarded as belonging to the same great period in the history of life upon the globe, and are said to be "geologically contemporaneous." The term "homotaxis" was proposed by Huxley[1] to express the idea that the general sequence of life had been the same in each region, without implying that the same stage of development was everywhere synchronous. He thought that a definite stage like that of the Devonian in one country might have been coeval with another stage, say the Silurian, in another country, and with the Carboniferous in a third. This extreme position few geologists were disposed to accept. The subsequent progress of investigation has tended to confirm the older belief, that each great geological period was, in the broadest sense, contemporaneous over the globe, though it might begin earlier or end later in one region than in another. The various faunas are never inverted, but always follow the same order of succession all over the world.

On any theory of the origin of species, the spread of a species, still more of any group of species, to a vast distance from the original centre

[1] *Q. J. G. S.* xviii. (1862), p. xlvi.

of dispersion, must in most cases have been extremely slow. It doubtless occupied so prolonged a time as to allow of vast changes in physical geography. A species may have disappeared from its primeval birthplace, while it continued to flourish in one or more directions along its outward circle of advance. The date of the first appearance and final extinction of that species would thus differ widely, according to the locality at which we might examine its remains. Nevertheless, enormous though the lapse of time must have been to allow a species, a genus, or a fauna to become world-wide in distribution, it must have been vastly less than that during which the fauna flourished and underwent the slow biological evolution represented by a single geological formation, with its succession of life-zones. While the grand march of life, in its progress from lower to higher forms, has been broadly alike and in a vague sense simultaneous in all quarters of the globe, its rate of advance has not everywhere been the same. It has moved unequally over the same region. A certain stage of progress may have been reached in one quarter of the globe many thousands of years before it was reached in another; though the same general succession of organic types may be found in each region. There seems to be now sufficient evidence, for example, to warrant the assertion that the progress of terrestrial vegetation has at some geological periods and in some regions, been in advance of that of the marine fauna (see p. 848). Hence arise anomalies in the attempts to group the geological formations of distant countries in conformity with European standards. As Dr. Blanford has well remarked, "in instances of conflicting evidence between terrestrial or freshwater faunas and floras on the one side, and marine faunas on the other, the geological age indicated by the latter is probably correct, because the contradictions which prevail between the evidence afforded by successive terrestrial and freshwater beds are unknown in marine deposits; because the succession of terrestrial animals and plants in time has been different from the succession of marine life; and because in all past times the differences between the faunas of distant lands have probably been, as they now are, vastly greater than the differences between the animals and plants inhabiting the different seas and oceans."[1]

3. Geographical Distribution of Plants and Animals.—As the plants and animals now living on the surface of the globe are the descendants of those that flourished in earlier periods, it is obvious that in order to understand how they have come to be distributed as we now

[1] In his suggestive address to the Geological Section of the British Association at the Montreal meeting, from which the above quotation is taken, Dr. Blanford gives some examples of the contradictions involved in attempts to correlate distant deposits by means of land and freshwater faunas and floras. The Damuda beds of India, as he points out, contain a flora with Middle Jurassic affinities, but the fauna of the overlying Panchet beds is rather Triassic or even Permian. Still more striking was the example furnished by the Lower Coal-measures of New South Wales, where plants which botanists believed to be of Jurassic types were found in the same stratified deposits with undoubted Carboniferous Limestone marine organisms (*Orthoceras*, *Conularia*, *Spirifer*, *Fenestella*, &c.). This author returned to the subject in his presidential addresses to the Geological Society. *Q. J. G. S.* xlv. (1889), p. 72; xlvi. (1890), p. 110. See postea on the *Glossopteris* flora, Book VI. Part II. Sect. iv.

find them, we must know something of their ancestry and of their own history. Their derivation from other types of life that preceded them forms part of a vast subject which belongs rather to biology than to geology, but to which some brief allusion will be made in the next section of this Book (p. 845). The past history of the species and genera of living floras and faunas is embraced, however, within the province of the geologist in so far as it is from the evidence which he can collect that our knowledge is derived of the causes that have contributed to the present distribution of plants and animals. This evidence is drawn partly from the deposits in which the remains of living species have been preserved, and partly from a consideration of the changes of geography and climate which can be ascertained to have taken place in late geological time. An early and classical example of the application of geological investigation to the history of the flora and fauna of a country was the remarkable essay by Edward Forbes on the origin of those of Britain.[1] Arranging the vegetation of these islands into five separate floras, he traced out the geographical connection of each, and showed the order in which, as he believed, they had successively appeared. The oldest pointed, in his opinion, to a former land-connection between the west and south-west of Ireland and the north of Spain. The second showed an ancient prolongation of the south-west of England and south-east of Ireland across the Channel Isles into France. The third connected the Chalk Downs of the south-east of England with those of northern France. The fourth, restricted to the higher hills and mountains, was shown to be Scandinavian in character, and to have spread over the country during the time when an Arctic climate prevailed in northern and central Europe. The fifth or general flora was recognised as identical with that of central and western Europe, and to have come into Britain as the latest plant-migration of the whole. These early and suggestive generalisations of Forbes have been modified and extended by later research, but his luminous essay ought still to be read by every student who desires to obtain a broad and vivid conception of the way in which geological history may be made to interpret the distribution of the present plant and animal life of the earth's surface.[2]

The profound geological interest of the present geographical distribution of plants and animals has been indicated in some of the most important contributions to geological literature. Thus the subject was luminously treated by Darwin in chapters xii. and xiii. of his 'Origin of Species,' and by Lyell in chapters xxxviii. to xli. of his 'Principles of Geology.' It has been ably discussed by Mr. A. R. Wallace in his

[1] "On the Connexion between the Distribution of the existing Fauna and Flora of the British Isles and the Geological changes which have affected their area, especially during the epoch of the Northern Drift." *Mem. Geol. Surv.* i. (1846), pp. 336-432.

[2] The student, after studying this memoir, may with advantage turn to the little volume by Mr. Clement Reid, 'The Origin of the British Flora,' London, 1899, where he will find the subject discussed in the light of the vast amount of geological work that has been done since the pioneer work of Edward Forbes, whose generalisations were necessarily imperfect and in some respects erroneous.

works on the 'Geographical Distribution of Animals' (2 vols. 1876) and on 'Island Life' (1880).[1]

4. Imperfection of the Geological Record.[2] — Since the statement was made by Darwin, geologists have more fully recognised that the history of life has been very imperfectly chronicled in the stratified parts of the earth's crust. Apart from the fact that, even under the most favourable conditions, only a small proportion of the total flora and fauna of any period would be preserved in the fossil state, enormous gaps occur where, from non-deposit of strata, no record has been preserved at all. It is as if whole chapters and books were missing from a historical work. But even where the record may originally have been tolerably full, powerful dislocations have often thrown considerable portions of it out of sight. Sometimes extensive metamorphism has so affected the rocks that their original characters, including their organic contents, have been destroyed. Oftenest of all, denudation has come into play, and vast masses of strata have been entirely worn away, as is shown not only by the erosion of existing land-surfaces, but by the abundant unconformabilities in the structure of the earth's crust (p. 820).

While the mere fact that one series of rocks lies unconformably on the denuded surface of another, proves the lapse of an interval between them, the relative length of this interval may sometimes be demonstrated by means of fossil evidence, and by this alone. Let us suppose, for example, that a certain group of formations has been disturbed, upraised, denuded, and covered unconformably by a second group. In lithological characters, the two may closely resemble each other, and there may be nothing to show that the gap represented by their unconformability is of an important character. In many cases, indeed, it would be quite impossible to pronounce any well-grounded judgment as to the length of interval, even measured by the vague relative standards of geological chronology. But if each group contains a well-preserved suite of organic remains, it may not only be possible, but easy, to say how much of the known geological record has been left out between the two sets of formations. By comparing the fossils with those obtained from regions where the geological record is more complete, it may be ascertained, perhaps, that the lower rocks belong to a certain platform or stage in geological history which, for our present purpose, we may call D, and that the upper rocks can, in like manner, be paralleled with stage H. It would be then apparent that, at this locality, the chronicles of three great geological periods, E, F, and G, were wanting, which are elsewhere found to be intercalated between D and H. The lapse of time represented by this unconformability would thus be equivalent to that required for the accumulation of the three missing series in those regions where, sedimentation having been more continuous, the record of them has been preserved.

[1] Among the treatises in which this subject is dealt with reference may again be made to those of Professor Gaudry, cited on p. 824. The history of the fauna of Europe has been ably investigated by Dr. R. F. Scharff (*Proc. Roy. Irish Acad.* 1897, pp. 427-514, and his separate volume on 'The History of the European Fauna,' 1899).

[2] See p. 855.

But fossil evidence may be made to prove the existence of gaps which are not otherwise apparent. As has been already remarked, changes in organic forms have probably been, on the whole, extremely slow in the geological past. The whole species of a sea-floor could not pass entirely away, and be replaced by other forms, without the lapse of long periods of time. If, then, among the conformable stratified deposits of former ages, we encounter abrupt and important changes in the facies of the fossils, we may be certain that these must mark omissions in the record, which we may hope to fill in from a more perfect series elsewhere. The striking palæontological contrasts between unconformable strata are sufficiently explicable. It is not so easy to give a satisfactory account of those which occur where the strata are strictly conformable, and where no evidence can be observed of any considerable change of physical conditions at the time of deposit. A group of quite conformable strata, having the same general lithological characters throughout, may be marked by a great discrepance between the fossils of the upper and the lower part. A few species may pass from the one into the other, or perhaps every species may be different. In cases of this kind, when proved to be not merely local but persistent over considerable areas, we must admit, notwithstanding the apparently undisturbed and continuous character of the original deposition of the strata, that the abrupt transition from the one facies of fossils to the other represents a long interval of time which has not been recorded by the deposit of strata. Sir A. C. Ramsay, who called attention to these gaps, termed them "breaks in the succession of organic remains."[1] They occur abundantly among the European Palæozoic and Secondary rocks, which, by means of them, can be separated into zones and sections (see *postea*, p. 860). But though traceable over wide regions, they were probably not general over the whole globe. So far as geological evidence can show, there have never been any universal interruptions in the continuity of the chain of being. The breaks or apparent interruptions no doubt exist only in the sedimentary record, and may have been produced by geological agencies of various kinds, such as cessation of deposit from failure of sediment owing to seasonal or other changes; alteration in the nature of the sediment or character of the water; variations of climate from whatever cause; elevation or subsidence by subterranean movements, bringing successive submarine zones into less favourable conditions of temperature, &c.; and volcanic discharges. The physical revolutions, which brought about the breaks, were no doubt sometimes general over a whole zoological province, more frequently over a minor region. Thus, at the close of the Triassic period the inland basins of central, southern, and western Europe were effaced, and another and different geographical phase was introduced which permitted the spread of the peculiar fauna of the "Avicula contorta zone" from the south of Sweden to the plains of Lombardy, and from the north of Ireland to the eastern end of the Alps. This phase in turn disappeared to make way for the Lias with its numerous "zones," each distinguished by the maximum development of one or more species of

[1] *Q. J. G. S.* xix. xx. Presidential Addresses.

ammonite.[1] These successive geographical revolutions must, in many cases, have caused the complete extinction of genera and species possessing a small geographical range. Nevertheless, it must be admitted that in many instances where fossil species have a wide geographical extension, but a limited stratigraphical range, such as the species of Silurian graptolites and Jurassic ammonites, no satisfactory evidence has been adduced to connect the change of species with geographical revolutions. There may be some biological law not yet perceived, which has governed such organic mutations.

It is abundantly clear, however, that the geological record, as it now exists, is at the best but an imperfect chronicle of geological history. In no country is it complete. The lacunæ of one region may be supplied from another; yet in proportion to the geographical distance between the localities where the gaps occur and those whence the missing intervals are supplied, the element of uncertainty in our reading of the record is increased. The most desirable method of research is to exhaust the evidence for each area or province, and to compare the general order of its succession as a whole, with that which can be established for other provinces. It is, therefore, only after long and patient observation and comparison that the geological history of different quarters of the globe can be correlated.[2]

5. **Subdivisions of the Geological Record by means of Fossils.**—As fossil evidence furnishes a much more satisfactory and widely applicable means of subdividing the stratified rocks of the earth's crust than mere lithological characters, it is made the basis of the geological classification of these rocks. Thus, a particular zone or group of strata may be ascertained to be marked by the occurrence in it of various fossils, one or more of which may be distinctive, either from occurring in no other zone or group, or from special abundance in that zone. These species may, therefore, be used as a guide to the occurrence of the zone in question, which may be called by the name of the most abundant species. In this way, a geological horizon or zone is marked off, and geologists thereafter recognise its position in the geological series.[3] But before such a generalisation can be safely made, we must be sure that the species in question really never does characterise any other platform. This evidently demands wide experience over an extended field of observation. The assertion that a particular species or genus occurs only on one horizon, or within certain limits, manifestly rests on negative evidence as much as on positive. The palæontologist who makes it cannot mean more than that he knows the species or genus to lie on that horizon, or

[1] Consult on this subject the memoirs on Jurassic geography of the late Professor Neumayr, quoted *ante*, pp. 834, 835.

[2] For an example of the working out from fossil evidence of the history of the various provinces or regions of a large area of the earth's surface during an ancient geological period, see the digest given by Professor Hyatt of what is known of the Jurassic tracts of Europe, in his essay on the 'Genesis of the Arietidæ,' chap. iv.

[3] This subject is more fully discussed in the introductory part of Book VI., which treats of Stratigraphical Geology.

within those limits, and that, so far as his own experience and that of others goes, it has never been met with beyond the limits assigned to it. But a single instance of the occurrence of the fossil in a different zone would greatly damage the value of his generalisation, and a few such cases would demolish it altogether. The genus *Arethusina*, for example, had long been known as a characteristic trilobite of the lower zones of the third or highest fauna of the Bohemian Silurian basin. So abundant is one species (*A. Konincki*) that Barrande collected more than 6000 specimens of it, generally in good preservation. But no trace of it had been met with towards the upper limit of the Silurian fauna. Eventually, however, a single specimen of a species so nearly identical as to be readily pronounced the same was disinterred from the upper Devonian rocks of Westphalia—a horizon separated from the upper limit of the genus in Bohemia by at least half of the vertical height of the Upper Silurian and by the whole of the Lower and Middle Devonian rock-groups.[1] Such an example showed the danger of founding too much on negative data. To establish a geological horizon on limited fossil evidence, and then to assume the identity of all strata containing the same fossils, is to reason in a circle, and to introduce utter confusion into our interpretation of the geological record. The first and fundamental point is to determine accurately the superposition of the strata. Until this is done, detailed palæontological classification may prove to be worthless.

From what has been above advanced, it must be evident that, even if the several groups in a series or system of rocks in any district or country have been found susceptible of minute subdivision by means of their characteristic fossils, and if, after the lapse of many years, no discovery has occurred to alter the established order of succession of these fossils, nevertheless the subdivisions may only hold good for the region in which they have been made. They must not be assumed to be strictly applicable everywhere. Advancing into another district or country, where the petrographical characters of the same formation or system indicate that the original conditions of deposit must have been very different, we ought to be prepared to find a greater or less departure from the first observed, or what we unconsciously and not unnaturally come to look upon as the normal, order of organic succession. There can be no doubt that the appearance of new organic forms in any locality has been in large measure connected with such physical changes as are indicated by diversities of sedimentary materials and arrangements. The Upper Silurian stages, for example, as studied by Murchison in Shropshire and the adjacent counties, present a clear sequence of strata well defined by characteristic fossils. But within a distance of sixty miles, it becomes impossible to establish all these subdivisions by similar fossil evidence. Again, in Bohemia and in Russia we meet with still greater departures from the order of appearance in the original Silurian area, some of the most characteristic Upper Silurian organisms being there found beneath strata replete with records of Lower Silurian life. Nevertheless, the general succession of life from

[1] Barrande, 'Réapparition du genre Arethusina,' Prague, 1868.

Lower to Upper Silurian types remains distinctly traceable. Still more startling are the anomalies, already referred to, where the succession of terrestrial organisms in distant regions is compared with that of the associated marine forms; as where, in Australia, a flora, with what had been regarded as Jurassic affinities, was contemporaneous with a Carboniferous fauna. Such facts warn us against the danger of being led astray by an artificial precision of palæontological detail. Even where the palæontological sequence is best established, it rests, probably in most cases, not merely upon the actual chronological succession of organic forms, but also, far more than is usually imagined, upon original accidental differences of local physical conditions. As these conditions have constantly varied from region to region, it must comparatively seldom happen that the same minute palæontological subdivisions, so important and instructive in themselves, can be identified and paralleled, except over comparatively limited geographical areas. The remarkable "zones" of the Lias, for instance, in central and western Europe, cease to be traceable as we recede from their original geographical province.

§ v. **Bearing of Palæontological data upon Evolution.**—Since the researches of William Smith at the end of last century, it has been well understood that the stratified portion of the earth's crust contains a suite of organic remains in which a gradual progression can be traced, from simple forms of invertebrate life among the older rocks to the most highly differentiated mammalia of the present time. Until the appearance of Darwin's 'Origin of Species' in 1859, the significance of this progression, and its connection with the biological relations of existing faunas and floras were only dimly perceived, though Lamarck had proposed a theory of development, in support of which appeals had been made to the organic succession revealed by the geological record. Darwin, arguing that, instead of being fixed or but slightly alterable forms, species might be derived from others, showed that processes were at work, whereby it was conceivable that the whole of the existing animal and vegetable worlds might have descended from, at most, a very few original forms. From a large array of facts, drawn from observations made upon domestic plants and animals, he inferred that, from time to time, slight peculiarities due to differences of climate, &c., appear in the offspring which were not present in the parent, that these peculiarities may be transmitted to succeeding generations, especially where from their nature they are useful in enabling their possessors to maintain themselves in the general struggle for life. Hence varieties, at first arising from accidental circumstances, may become permanent, while the original form from which they sprang, being less well adapted to hold its own, perishes. Varieties become species, and specific differences pass in a similar way into generic. The most successful forms are, by a process of "natural selection," made to overcome and survive those that are less fortunate, the "survival of the fittest" being the general law of nature. The present varied life of the globe may thus, according to Darwin, be explained by the continued accumulation, perpetuation, and increase of differences in the evolution of plants and animals during the whole of

geological time. Hence the geological record should contain a more or less full chronicle of the progress of this long history of development.

It is now well known that in the embryonic development of animals, there are traces of a progress from lower or more generalised to higher or more specialised types. Since Darwin's great work appeared, naturalists have devoted a vast amount of research to this subject, and have sought with persevering enthusiasm for any indications of a relation between the order of appearance of organic forms in time and in embryonic development, and for evidence that species and genera of plants and animals have come into existence in the order which, according to the theory of evolution, might have been anticipated.

It must be conceded that, on the whole, the testimony of the rocks is in favour of the doctrine of evolution. That there are difficulties still unexplained, must be frankly granted. Darwin strongly insisted, and with obvious justice, on the imperfection of the geological record, as one great source of these difficulties. Objections to the development theory have been drawn from the observed order of succession of plants, and the supposed absence of transitional forms among them. Ferns, equisetums, and lycopods, it is affirmed, appear as far back as the Old Red Sandstone, not in simple or more generalised, but in more complex structures than their living representatives. The earliest known conifers were well-developed trees, with woody structure and fruits as highly differentiated as those of the living types. The oldest dicotyledons yet found, those of the Cretaceous formations, contain representatives of the three great divisions of *Apetalæ*, *Monopetalæ*, and *Polypetalæ* in the same deposit. These "are not generalised types, but differentiated forms which, during the intervening epochs, have not developed even into higher generic groups."[1]

Professor A. Agassiz has drawn attention to the parallelism between embryonic development and palæontological history. Taking the sea-urchins as an illustrative group, he points out the interesting analogies between the immature conditions of living forms and the appearance of corresponding phases in fossil genera. He admits, however, that no early type has yet been discovered whence star-fishes, sea-urchins, or ophiurans might have sprung; that the several orders of echinoderms appear at the same time in the geological record, and that it is impossible to trace anything like a sequence of genera or direct filiation in the palæontological succession of the echinids, though he does not at all dispute the validity of the theory which regards the present echinids as having come down in direct succession from those of older geological times.[2] In the case of the numerous genera which have continued to exist without interruption from early geological periods, and have been termed "persistent types," it is impossible not to admit that the existing forms are the direct descendants of those of former ages. If, then, some genera have unquestionably been continuous, the evolutionist argues, it may reasonably be inferred that continuity has been the law, and that even where the successive steps of the change cannot be traced, every genus of the living world is genetically related to other genera now extinct.

Professor A. Hyatt, who has closely studied the Cephalopoda, regards them as furnishing clear evidence of evolution. Returning to some of the ideas of Lamarck on development, he concludes that "the efforts of the orthoceratite to adapt itself fully to the requirements of a mixed habitat, gave the world the Nautiloidea; the efforts of the

[1] W. Carruthers, *Geol. Mag.* 1876, p. 362. Further study, however, has shown the existence of early generalised types such as the Cordaitaceæ which unite some of the characters of conifers, cycads, and ferns.

[2] *Ann. Mag. Nat. Hist.* Nov. 1880, p. 369. "Report on Echinoidea," *Challenger* Expedition, iii. p. 19. The phyllogeny of the Graptolites was treated of by the late Professor H. A. Nicholson and J. Marr, *Geol. Mag.* 1895, p. 529.

same type to become completely a littoral crawler, developed the Ammonoidea." He thinks that, on the whole, the observed sucession of the organisms in time coincides with what on the theory of evolution it ought to have been. "The straight cones predominate in Silurian and earlier periods, while the loosely coiled are much less numerous, and the close-coiled and involute, though present, are extremely rare." He believes that traces of this succession may be found in the structure of the shells themselves. The nautilus, in its embryological development and subsequent growth, passes through the stages of the nearly or quite straight shell, then of a slightly curved shell, and then of a completely curved shell, the spiral being continued till sometimes the inner whorls are entirely enveloped in the outer.[1]

Neumayr, from a prolonged study of European Jurassic and Cretaceous cephalopods, concluded that "propagation, filiation, and migration are sufficient to explain the origin of the whole Jurassic Ammonite and Belemnite fauna of central Europe. There is nothing to warrant the supposition of any new creation, but all the known facts are in harmony with the theory of descent."[2]

Among the fossil mammalia many indications have been pointed out of an evolution of structure. Of these, one of the best known and most striking is the genealogy of the horse, as worked out by Professor O. C. Marsh.[3] The original, and as yet undiscovered, ancestor of our modern horse had five toes on each foot. In the oldest known equine type (Eohippus—an animal about the size of a fox, belonging to the early part of the Eocene period) there were four well-developed toes, with the rudiment of a fifth, on each fore-foot, and three on each hind-foot. In a later part of the same geological period appeared the Orohippus, a creature of about the same size, but with only four toes in front and three behind. Traced upwards into younger divisions of the Tertiary series, the size of the animal increases, but the number of digits diminishes, until we reach the modern Equus, with its single toe and rudimentary splint-bones.

Another remarkable example, that of the camels, was cited by Professor E. D. Cope. The succession of genera is seen in the same parts of the skeleton as in the case of the horse. The metatarsal and metacarpal bones are or are not co-ossified into a cannon bone ; the first and second superior incisor teeth are present, rudimentary or wanting,

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[1] *Science*, iii. (1884), pp. 122, 145. For an elaborate presentation of his views see his essay on the 'Genesis of the Arietidæ,' *Mem. Mus. Comp. Zool. Harvard.* xvi. (1889), where full references to the literature of the subject treated of by him will be found. See also A. H. Foord, *Geol. Mag.* 1895, p. 391. The evolution of the Brachiopoda is discussed by Miss A. Crane, *Geol. Mag.* 1895, pp. 65, 103.

[2] *Jahrb. Geol. Reichsanst.* xxviii. (1878), p. 78 ; also *Abhandl. Geol. Reichsanst.* 1873 ; *Sitzb. K. Akad. Wiss. Wien*, lxxi. (1875), p. 639. *Verh. Geol. Reichsanst.* 1880, p. 83 (in reply to the anti-Darwinian views of T. Fuchs, *op cit.* 1879, 1880), and his memoirs already cited on pp. 834, 835. W. Branco, *Z. D. G. G.* xxxii. (1880), p. 596. An example of the tracing of pedigree among trilobites was supplied by R. Hoernes, *Jahrb. Geol. Reichsanst.* xxx. (1880), p. 651. On the geological history and affiliations of the Palæozoic invertebrates, the student should consult Professor Gaudry's 'Les Enchaînements du Monde Animal : Fossiles Primaires,' 1883. Coming up into the ranks of the vertebrates he will find the bearing of the history of fossil fishes on evolution discussed by Dr. Traquair in his Address to the Zoological Section of British Association 1900.

[3] *Amer. Journ. Sci.* 1879, p. 499. Consult also his interesting paper on "Recent Polydactyle Horses," *op. cit.* xlii. (1892), p. 339, and his paper on the "Origin of Mammals," *Geol. Mag.* 1899, p. 13. There is a valuable essay by Professor K. von Zittel on the "Geological Development, Descent and Distribution of the Mammalia," *Geol. Mag.* 1893, pp. 401-412, 455-468, 501-514, translated from *Sitz. Bayer. Akad.*, Munich, xxiii. (1893) ; and another by Professor Osborn on "The Rise of the Mammalia in North America," *Amer. Journ. Sci.*, Nov., Dec. 1893, *Nature*, xlix. (1894), p. 235. See also the volume by Dr. Scharff, cited *ante*, p. 841.

and the premolar number from four to one. The chronological succession of genera was given by Cope as follows:

	No cannon bone.	Cannon bone present.		
	Incisor teeth present.	Incisors 1 and 2 wanting.		
	4 premolars.	3 premolars.	2 premolars.	1 premolar.
Lower Miocene . .	Poëbrotherium.			
Upper Miocene . .	Protolabis. Procamelus.	Pliauchenia.		
Pliocene and recent			Camelus.	Auchenia.

According to this table, the Camelidæ have gradually undergone a consolidation of the bones of the feet, with a great reduction in the number of the incisor or premolar teeth. Cope indicated an interesting parallel between the palæontological succession and the embryonic history of the same parts of the skeleton in the living camel.[1] Among the Carnivora, as M. Gaudry has pointed out, it is possible not only to trace the ancestry of existing species, but to discover traits of union between genera which at present seem far removed.[2] The same distinguished palæontologist has shown the interesting dental evolution between the teeth of the Middle Miocene *Mastodon* and those of the post-Pliocene Mammoth, and again between those of the Lower Oligocene *Amphicyon* and those of the Quaternary cave-bear.[3]

It is not necessary here to enter more fully into the biological aspect of this wide subject. While the doctrine of evolution has now obtained the assent of the great majority of naturalists all over the globe, even the most strenuous upholder of the doctrine must admit that it is attended with palæontological difficulties which no skill or research has yet been able to remove. The problem of derivation remains insoluble, nor perhaps may we hope for any solution beyond one within the most indefinite limits of correctness.[4] But to the palæontologist, it is a matter of the utmost importance to feel assured that, though he may never be able to trace the missing links in the chain of being, the chain has been unbroken and persistent from the beginning of geological time.

It was remarked above (p. 839) that, while the general march of life has been broadly alike all over the world, progress has been more rapid in some regions, and likewise in some grades of organic being, than in others. The evolution of terrestrial plants and animals appears to have been much less uniform than that of marine life, at least than that of the marine mollusca. It has been suggested that the climatic changes, which have had so dominant an influence in evolution, would affect land-plants before they influenced marine animals. Certainly a number of instances are known where an older type of marine fauna is associated

[1] *American Naturalist*, 1880, p. 172. M. Gaudry traces an analogous process in the foot-bones of the ruminants of Tertiary time, 'Les Enchaînements du Monde Animal,' i. p. 121.

[2] *Op. cit.* p. 210.

[3] 'Essai de Paléontologie Philosophique,' p. 188, *et seq.* Compare also his paper on the dentition of man and certain animals, *Anthropologie*, xii. (1901), pp. 1 and 513.

[4] A. Agassiz, *Ann. Mag. Nat. Hist.* 1880, p. 372.

with a younger type of terrestrial flora. Besides those already cited (p. 839), reference may be made to the flora of Fünfkirchen in Hungary, which, though Triassic in type, occurs in strata which have been classed with the Palæozoic Zechstein; and to the Upper Cretaceous flora of Aix-la-Chapelle, which, with its numerous dicotyledons, has a much more modern aspect than the contemporaneous fauna. In the Western Territories of North America, much controversy at one time arose as to the position of the "Laramie series," its rich terrestrial flora having an undoubted Tertiary facies, while its fauna is Cretaceous. According to Th. Fuchs, the most important turning-point in the history of the plant-world is to be found not, as in the case of the terrestrial fauna, between the Sarmatian stage and the *Congeria*-beds, but on an older horizon, namely between the first and second Mediterranean stage.[1] Nor is this intercalation of types characteristic of other periods entirely confined to the vegetable world. Examples may be found of survivals of types of terrestrial animals when the contemporaneous marine fauna has become distinctly more modern. The present mammals of Australia and New Guinea are more allied to forms that lived in Mesozoic time than to those now living in other countries. The remarkable mammalian fauna of Pikermi, with Miocene affinities, has been found to lie upon strata containing Pliocene marine shells.

From what has now been stated, it will be understood that the existence of any living species or genus of plant or animal, within a certain geographical area, is a fact which cannot be explained except by reference to the geological history of that species or genus. The existing forms of life are the outcome of the evolution which has been in progress during the whole of geological time. From this point of view, the investigations of palæontological geology are invested with the profoundest interest, for they bring before us the history of that living creation of which we form a part.

§ **vi. The Collecting of Fossils.**—Some practical suggestions regarding the search for fossils may be of service to the student. Any sedimentary rock may possibly enclose the remains of plants or animals. All such rocks should therefore be searched for fossils. A little practice will teach the learner that some kinds of sedimentary rocks are much more likely than others to yield organic remains. Limestones, calcareous shales, and clays are often fossiliferous; coarse sandstones and conglomerates are seldom so. Yet it will not infrequently be found that rocks which might be expected to contain fossils are barren, while even coarse conglomerates may, in rare cases, yield the teeth and bones of vertebrates or other durable relics of once living things. The peculiarities of the rocks of each district must, in this respect, be discovered by actual careful scrutiny.

As organic remains usually differ more or less, both in chemical composition and in minute texture, from the matrix in which they are imbedded, they weather differently from the surrounding rock. In some instances, where they are more durable, they project in relief from a weathered surface; in others they decay, and leave, as

[1] E. Weiss, *Neues Jahrb.* 1878, p. 180; also *Z. D. G. G.* xxix. p. 252.

cavities, the moulds in which they have lain. One of the first requisites, therefore, in the examination of any rock for fossils is a careful search of its weathered parts. In the great majority of cases, its fossiliferous or non-fossiliferous character may thereby be ascertained.

When indications of fossils have been obtained, the particular lithological characters of the part of the rock in which they occur should be noted. It will often be found that the fossils are either confined to, or are more abundant and better preserved in, certain zones. These zones should be explored before the rest of the rock is examined in detail. Where fossils decay on exposure, the rock containing them must be broken open so as to reach its fresher portions. Where the rock is not disintegrated in weathering, it must likewise be split up in the usual way. But where it crumbles under the influence of the weather, and allows its fossils to become detached from their matrix, its débris should be examined. Shales and clays are particularly liable to this kind of disintegration, and are consequently deserving of the fossil-collector's closest attention, since from their decaying surfaces he may often gather the organisms of past times, as easily as he can pick up shells on the present sea-shore.

But the task of the collector does not end when he has broken open several tons, perhaps, of fresh rock, and has searched among the weathered débris until he can no longer meet with any forms he has not already found. In recent years, methods have been devised for enabling him to extract the minuter organisms from rocks. Some of these methods are described in the following pages. They show that a deposit, otherwise supposed to be unfossiliferous, may be rich in foraminifera, entomostraca, &c., so that, besides the abundant fossils readily detected by the naked eye in a rock, there may be added a not less abundant and varied collection of microzoa.[1]

As each variety of rock has its own peculiarities of structure, which may vary from district to district, the appliances of the fossil collector must likewise be varied to suit local requirements. The following list comprises his most generally useful accoutrements; but his own judgment will enable him to modify or supplement them according to his needs:—

List of Appliances useful in Fossil-collecting.

1. Several hammers, varying in size according to the nature of the rocks to be examined. Where these are tough and hard, a hammer weighing 2 lbs. may be needed. A small trimming hammer (6 oz.) for reducing the size of specimens is essential.
2. Several chisels of different sizes and shapes.
3. A small pick weighing 1 lb., useful for loosening blocks of rocks from their bed.
4. A small trowel, used for scooping up weathered débris of shale, &c.
5. A gardener's spade with circular cutting edge; of use in lifting slabs of shale.
6. Pair of strong pincers, like those used for cutting wire, for reducing specimens which might go to pieces under a blow of a hammer.
7. A collecting-bag (canvas or leather).
8. A supply of nests of pill-boxes for more delicate specimens.
9. Brown and softer grey wrapping paper (old newspapers are serviceable).
10. Gummed labels, numbered to correspond with those in the collecting-book.
11. Note-book or collecting-book, in which, where practicable, each specimen is entered under its number, with all particulars of its exact locality, geological horizon, &c.
12. Fish-glue, a thin solution of which is useful to preserve specimens that may be liable to crack into pieces.

[1] The following descriptions of methods of searching for fossil microzoa have been drawn up from notes for which I was indebted to the late Mr. James Bennie, Fossil Collector of the Geological Survey of Scotland, who was singularly successful in increasing our knowledge of the minuter forms of animal life in the Carboniferous system.

To these simple appliances others of a more recondite nature have been added by various palæontologists. Thus M. Lemoine has employed the Röntgen rays as a means of discovering the existence of bones or other organisms in the heart of an unbroken block of stone.[1] Mr. Bernard has recommended the adoption of the artificial sand-blast as an effective method of developing trilobites from amidst the matrix in which they are imbedded.[2] Obviously the ingenuity of the collector will suggest the best means of obtaining the results he desires.

Weathered Shales. The heaps of shale thrown out in quarrying operations, afford excellent ground for fossil hunting. It is best to begin at the bottom of a heap, and to creep slowly along the same level for a dozen yards or so, where the ground to be examined is extensive; then to return along a band slightly higher, and so on backward and forward until the top is reached, which may be searched in breadths of a yard at a time. In this way, the more prominent fossils may be obtained. Large and thin fossils, such as shells of *Pecten*, *Modiola*, &c., which break into fragments in weathering, must be sought for in the less-decayed parts of the shale. When found, the matrix around them should be reduced to the desired size by means of pincers. They should then be wrapped up in a box, or, at least, secured against injury in the homeward transport, and as soon as possible thereafter should be dipped in a thin solution of fish-glue and allowed to dry slowly in the air. As a rule, particularly where the structure of a fossil is well-preserved, it is desirable to retain also the surface of rock containing its impression, which not infrequently affords evidence of structure that may be less distinctly preserved on the counterpart, or side to which the main portion of the fossil has adhered.

Some fossils of great delicacy, such as fronds of *Fenestella*, which go to pieces as the rock weathers, may be extracted by an ingenious process devised by the late Mr. John Young, Curator of the Hunterian Museum, Glasgow University. If the shale on which such organisms lie is liable to go to pieces, it may be sufficiently secured for transport by being coated with a thin solution of gum, which is allowed to dry before the specimen is packed up. If the actually exposed face of the *Fenestella* is intended to be exhibited, it may be cleaned from the gum or from any adherent shale by being rubbed quickly with a wet nail-brush and wiped with a clean damp sponge, care being taken that the gum holding down the lower surface of the fossil is not softened, and that the shale does not get too wet. If, on the other hand, it is desirable to expose the face of the frond that adheres to the shale, this may be effected as follows. All trace of any gum that may have been used should be carefully removed. The specimen is then warmed before a fire, and a thin layer of asphalt is melted over it by means of a hot iron rod. If the frond to be lifted is large, a thick strong cake should be formed upon the specimen by using alternate layers of strong brown paper and asphalt, the paper always forming the outer surface of the cake. When the cohesion between the asphalt and the specimen is firm, the whole is then placed in water, when the shale generally crumbles down and can be removed, leaving the *Fenestella* adhering to the asphalt. In this way, the poriferous surface, which, for the most part, clings to the shale when the rock is broken open, is laid bare. By gently brushing the specimen with water, its minute structure may be revealed, the delicate network lying on the asphalt like a piece of lace upon a ground of black velvet. The cake of asphalt may then be shaped and mounted on a wooden tablet.[3]

But in most cases there are various minuter forms which escape notice, and which must be searched for in another way. To secure these, a little shale should be lifted with a trowel from the most weathered parts where fossils are visible, the trowel being gently pushed along so as to remove only the superficial layer, where the fossils are

[1] *B. S. G. F.* xxiv. (1896), p. 690. [2] *Geol. Mag.* 1894, p. 553.

[3] Mr. Young kindly revised for me this account of his asphalt-process.

necessarily more abundant from the disintegration and removal of the shale by rain, sun, and wind. If wet, the shale thus collected should be thoroughly dried in an oven or before a fire. Thereafter, it is to be well soaked in water till it crumbles down; after gentle agitation, the muddy water should be poured off, the heavier particles being allowed to settle to the bottom. This process should be repeated till the sediment is so freed from clayey particles that it can be passed through sieves of different degrees of fineness. The several assortments thus obtained should then be boiled separately in a rather broad-bottomed goblet over a brisk fire for about half an hour, the boiling being continued with a change of water till little or no mud appears. The coarser parcels may then be dried and spread out on a school-slate, when, with lens and a camel-hair brush wetted at the point, the fossils may be easily picked out and dropped into a pill-box for further examination. The finer kinds may be separated into lighter and heavier portions by putting, say, a handful of the thoroughly dried sediment into a bowl, and turning a gentle stream of water upon it, when the lighter grains float and may be decanted into another vessel. These floated parts include the smaller kinds of foraminifera and entomostraca, the plates, anchors, crosses, and other spicules of holothurians and sponges, fragments of polyzoa, shells, &c. The effect of boiling is to loosen these organisms from the matrix and to clean them more perfectly than can be done in any other way; the minuter forms float off as dust. By this method of detection and selection, fossils which occur only in the proportion of one in a thousand of the particles may be easily secured.

Unweathered Shales.—It often happens that along cliff-sections, on the banks or beds of rivers or on the sea-shore, fossiliferous shales occur from which the weathered portions are continually washed or blown away, so that no opportunity occurs of adequately collecting the fossils from the exposed débris of the rocks. In such cases the solid, unweathered shale must be taken and treated somewhat differently. All layers of shale will not be found to be equally rich in microzoa, and it is desirable to try those first which seem most likely to yield satisfactory results—such, for instance, as those which are otherwise most fossiliferous. Where shale occurs in association with limestone, the portions just beneath or above the limestone should first be searched. The parts selected should be dried as thoroughly as possible in an oven or before a fire, and should then be put into water, and left there until they fall to pieces. The débris thus obtained is to be put into a rather wide-meshed sieve, and the coarser materials left behind may be again dried and steeped, this process being repeated two or three times, or until the fragments undergo no further subdivision. When thus reduced as much as possible, the débris should be boiled as above described. Some shales are completely disintegrated at once by boiling; others only after prolonged boiling, while some, though subdivided into small fragments, will not "dissolve," that is, will not break up into such fine particles as to remain in mechanical suspension in the water. Such obdurate varieties must be examined in bulk. In the Carboniferous system, the shales that boil down completely are those in which their component argillaceous particles have been compacted merely by pressure, or with such light cementation as could be destroyed by boiling. They are usually grey beds, such as so often accompany limestones. The black shales, on the other hand, containing a considerable proportion of bituminous cement, will not thoroughly break up even after prolonged boiling.

The drying and steeping here described may be regarded as processes of rapid artificial weathering. The effects of the heat of a fire upon shale resemble those of the sun's rays, and the soaking in water is a counterpart of the action of rain. It is surprising how easily hard, compact shale, which can with difficulty be broken or split with a hammer, may, by the method above specified, be reduced to dust or to fine granular débris, from which even delicate shells may easily be picked out entire. One may thus experimentally learn how important a part in the disintegration of rocks must be taken by the alternate desiccation and saturation of their surfaces by sunshine and shower.

Limestone and Ironstone.—Among fossiliferous limestones, remarkable differ-

ences are observable in the lithological condition of the enclosed fossils, and in the ease with which they can be recognised and extracted. It is only by diligent practice that these peculiarities can be so mastered as to enable the observer to make an exhaustive collection from the rocks which he explores. In some limestones, the organic remains are specially abundant in particular layers or pockets. Fragments of these parts of the rock may be taken home, and their fossils may be extracted by fixing the block on a piece of lead 1 inch thick and about 6 inches square, and cutting out the desired specimens with hammer and chisel. Entomostraca, and other small organisms in which the valves are united, may also be obtained in a perfect condition from this class of rocks, by pounding fragments of the fossiliferous material with a hammer within the circle of a small iron ring or "washer," one-eighth of an inch in thickness. As the rock is crushed by the blows of the hammer the organisms jump out of the matrix, but are retained within the bounds of the ring, which also answers as a gauge, preventing the material from being broken too small. The pounded rock is afterwards washed free from dust, dried and searched as above directed. Many limestones reveal their fossils best on weathered surfaces. In such cases, it not infrequently happens that the upper part of the rock immediately below the soil or subsoil yields a richer harvest of good specimens than could be obtained by breaking open the fresh stone. Some of the rotten débris from the surface and fissures of the limestone should be carried home, washed and boiled, as in the treatment of shale. The minuter organisms may thus be recovered, and as these, when found in limestone, often differ in kind from those preserved in shale, no opportunity should be lost of searching for them. Soft, pulverulent limestones, such as chalk, should be gently levigated, the chalky water being poured off and fresh water being added, until a granular residue of foraminifera, ostracods, shell fragments, &c., is obtained. Nodules of limestone or ironstone often enclose fossils, but it is not always easy to split them open in such a way as to lay bare their organic nucleus. This, however, may frequently be effected by putting the nodule into a fire, and dropping it, when quite hot, into cold water.

Clays.—These may be successfully treated for microzoa in the manner above described for shales.[1] Though they often contain much interstitial moisture they are not readily levigated in water until after they have been thoroughly dried in an oven, before a fire, or in the sun. When so treated they are easily reduced to fine mud, which may be removed in suspension until a granular residue is left, which may be searched for fossils. But as many of the minuter organisms float when loosened from the matrix, the muddy water should be passed through a brass-wire sieve as fine as muslin. If the meshes become clogged, so that the water will not flow readily through them, a few smart taps on the side of the sieve will clear them. Should some portions of the clay refuse to pass into muddy suspension, even after repeated trials, they will probably be levigated by boiling, as for shale. Treated as here recommended, many glacial clays, which, to the eye, appear hopelessly unfossiliferous, may thus be made to yield an interesting group of *Foraminifera*, *Entomostraca*, &c.[2]

Peat.—Much interesting information as to the climatal changes of former periods may be gleaned in temperate latitudes from a study of the organic remains preserved in peat-mosses. Below the peat there may lie layers of clay or marl preserving the remains of plants and animals, belonging possibly to an arctic climate. In such positions at various places in Central Scotland, thousands of fragments of the little Greenland crust-

[1] On the biological investigation of clays see H. Munthe, *Geol. Fören. Stockholm*, xvi. (1894), p. 17.

[2] By the methods here recommended large additions have been made to our knowledge of the microzoa of the past. (See, for example, Mr. H. B. Brady's researches on the Carboniferous *Foraminifera*, and Professor T. R. Jones's and Mr. Kirkby's monograph on Carboniferous *Entomostraca*.) The existence of *Holothuridae* in the Carboniferous sea was discovered entirely in this manner by the late James Bennie.

acean *Lepidurus* or *Apus*, together with leaves of arctic willow and birch, have been obtained. The bottom layers of the peat may also furnish northern species of plants. The upper spongy and fibrous part is of comparatively little interest, as it is made up of the common marsh plants still living in the surrounding country.[1]

[1] On the study of peat deposits see C. Reid in *Summary of Progress of Geological Survey* for 1898, p. 156. For methods of investigating the plants that form the substance of peat, see Gunnar Andersson, *Geol. Fören. Stockholm*, xiv. (1892), pp. 165 and 506; consult also the same author's papers on the preservation of Quaternary specimens of plants, *Op. cit.* xviii. p. 492, and his essay on the botanical examination of peat in *Svenska Mosskulturföres Tidsk.* 1893. A. G. Kellgren has described a new form of peat-borer, *Geol. Fören. Stockholm*, xvi. (1894), p. 372.

BOOK VI.

STRATIGRAPHICAL GEOLOGY.

THIS branch of the science arranges the rocks of the earth's crust in the order of their appearance, and interprets the sequence of events of which they form the records. Its province is to cull from other departments of geology the facts which may be needed to show what has been the progress of the planet, and of each continent and country on its surface, from the earliest times of which the rocks have preserved any memorial. Thus, from Mineralogy and Petrography, it obtains information regarding the origin and subsequent mutations of minerals and rocks. From Dynamical Geology, it ascertains by what agencies the materials of the earth's crust have been formed, altered, broken or upheaved. From Geotectonic Geology, it understands in what manner these materials have been built up into the complicated crust of the earth. From Palæontological Geology, it receives, in well-determined fossil remains, a clue by which to follow the relative chronology of stratified formations, and to trace the grand onward march of organised existence upon the planet. Stratigraphical geology thus gathers up the sum of all that is ascertained by other departments of the science, and makes it subservient to the interpretation of the past geological history of the earth.

The leading principles of stratigraphy have been indicated in the preceding pages, but may be summed up here as follows :—

1. In every stratigraphical research, the fundamental requisite is to establish the true or original order of superposition of the strata. Until this is accomplished by careful study of the actual relations of the rocks in the field, it is impossible to arrange relative dates and make out the sequence of geological history.

2. The stratified portion of the earth's crust, or Geological Record, may be subdivided into natural groups or "formations" of strata, each marked throughout by some common *facies* of organic remains, that is by the occurrence of some characteristic genera or species or a general resemblance in their palæontological type or character,[1] or, for limited tracts of country, by some common lithological features.

[1] The student may consult an interesting paper by Professor E. Renevier (*Arch. Sci.*

3. Living species of plants and animals can be traced downward into the more recent geological formations; but grow fewer in number as they are followed into more ancient deposits. With their disappearance, we encounter other species and genera which are no longer living. These in turn may be traced backward into earlier formations, till they too cease, and their places are taken by yet older forms. It is thus shown that the stratified rocks contain the records of a gradual progression of organic types. A species which has once died out does not seem ever to have reappeared.

4. When the order of succession of organic remains among the stratified rocks of a district or country has once been accurately determined on the basis of the true stratigraphical order, it becomes an invaluable guide in the investigation of the relative age and structural arrangements of these rocks, even in regions beyond that in which the organic succession has been first made out. Each zone or group of strata, being characterised by its own species or genera, may be recognised by their means, and the true succession of strata may thus be confidently established even in an area such as that of the Alps, wherein the rocks have been greatly fractured, folded, inverted, or metamorphosed.

5. This succession of organic remains is never inverted in any region. It may not be all represented in a particular country, but those parts which are represented always come in their proper order, save where they may have been subsequently disturbed by terrestrial movements.

6. The relative chronological value of the divisions of the Geological Record is not to be measured by mere depth of strata. While a great thickness of stratified rock may be reasonably assumed to mark the passage of a long period of time, it cannot safely be affirmed that a much less thickness elsewhere represents a correspondingly diminished period. The truth of this statement may sometimes be made evident by an unconformability between two sets of rocks, as has already been explained. The total depth of both groups together may be, say, 1000 feet. Elsewhere we may find a single unbroken formation reaching a depth of 10,000 feet; but it would be utterly erroneous to conclude that the latter must represent ten times the duration indicated by the two former. So far from this being the case, it might not be difficult to show that the minor thickness of rock really denotes by far the longer geological interval. If, for instance, it were proved that both the sections lie on one and the same geological platform, but that the lower series in the one locality belongs to a far older system of rocks than the base of the thick conformable series in the other, and that the upper unconformable series at the first place is of much later date than the upper portion of the thick series at the second, then it would be clear that the gap marked by the two thinner groups really indicates a longer period than the massive succession of deposits.

7. Fossil evidence furnishes the chief means of comparing the rela-

Phys. Nat. (Geneva, 1884, xii. p. 297) on "Geological Facies." The total mean depth of the fossiliferous formations or "Geological Record" in Europe has been set down at 75,000 feet, or upwards of 14 miles.

tive chronological value of groups of rock. A "break in the succession of organic remains" marks an interval of time often unrepresented by strata at the place where the break is found.[1] The relative importance of these breaks, and therefore, probably, the comparative intervals of time which they denote, may be estimated by the difference in the facies of the fossils on each side. If, for example, in one case we find every species to be dissimilar above and below a certain horizon, while in another locality only half of the species on each side of a band are peculiar, we naturally infer, if the total number of species seems large enough to warrant the inference, that the interval marked by the former break was longer than that marked by the latter. But we may go further, and compare by means of fossil evidence the relation between breaks in the succession of organic remains and the depth of strata between them.

Three series of fossiliferous strata, A, C, and H, may occur conformably above each other. By a comparison of the fossil contents of all parts of A, it may be ascertained that, while some species are peculiar to its lower, others to its higher portions, yet the majority extend throughout the group. If now it is found that, of the total number of species in the upper portion of A, only one-third passes up into C, it may be inferred with some probability that the time represented by the break between A and C was really longer than that required for the accumulation of the whole of the group A. It might even be possible to discover elsewhere a thick intermediate group B, filling up the gap between A and C. In like manner, were it to be discovered that, while the whole of the group C is characterised by a common suite of fossils, not one of the species and only one half of the genera pass up into H, the inference could hardly be resisted that the gap between the two groups marks the passage of a far longer interval than was needed for the deposition of the whole of C. And thus we reach the remarkable conclusion that, thick though the stratified formations of a country may be, in some cases they may not represent so long a total period of time as do the gaps in their succession,—in other words, that non-deposition has been in some areas more frequent and prolonged than deposition, or that the intervals of time which have been recorded by strata have sometimes not been so long as those which have not been so recorded.

In all speculations of this nature, however, it is necessary to reason from as wide a basis of observation as possible, seeing that so much of the evidence is negative. Especially needful is it to bear in mind that the cessation of one or more species, at a certain line among the rocks of a particular district, may mean nothing more than that, owing to some local change in the conditions of life or of deposition, these species were compelled to migrate, or became locally extinct, at the time marked by that line. They may have continued to flourish abundantly in neighbouring districts for a long period afterward. Many examples of this obvious truth might be cited. Thus, in a great succession of mingled marine, brackish-water, and terrestrial strata, like that of the Carboniferous Lime-

[1] See *ante*, p. 842, and the classic essays of the late Sir A. C. Ramsay there cited.

stone series of Scotland, corals, crinoids, and brachiopods abound in the limestones and accompanying shales, but grow fewer or disappear in the sandstones, ironstones, clays, and bituminous shales. An observer, meeting for the first time with an instance of this disappearance, and remembering what he had read about "breaks in succession," might be tempted to speculate about the extinction of these organisms, and their replacement by other and later forms of life, in the overlying strata. But further research would show him that, high above the plant-bearing sandstones and coals, lie other limestones and shales charged with the same marine fossils as before, and followed by still further groups of sandstones, coals, and carbonaceous beds and yet higher marine limestones. He would thus learn that the same organisms, after being locally exterminated, returned again and again to the same area when the conditions favourable for their migration reappeared and enabled them to reoccupy their former haunts. Such a lesson would probably teach him how largely the fauna entombed and preserved on any particular geological horizon has been influenced by the conditions of sedimentation, and that he should pause before too confidently asserting that the highest bed in which certain fossils can be detected, marks really their final appearance in the history of life. An interruption in the succession of fossils may be merely temporary or local, one set of organisms having been driven to a different part of the same region, while another set occupied their place until the first was enabled to return.

The remarkable limitation of certain species to a restricted vertical range in a continuous series of stratified deposits, as in the case of the Silurian graptolites and the Jurassic ammonites already cited, affords a valuable basis for stratigraphical arrangement and comparison. The succession of these species has been in some cases similar over such wide geographical areas that it is difficult to connect this organic sequence with any physical revolutions, of which indeed in a conformable series of sediments there may be little or no trace. As already suggested there may have been some biological law that governed these apparently rapid extinctions or replacements of organic forms, but which is not yet perceived or understood.

8. The Geological Record is at the best but an imperfect chronicle of the geological history of the earth. It abounds in gaps, some of which have been caused by the destruction of strata owing to metamorphism, denudation, or otherwise, some by original non-deposition, as above explained. Nevertheless it is from this record that the progress of the earth is chiefly traced. It contains the registers of the births and deaths of tribes of plants and animals, which have from time to time lived on the earth. Probably only an extremely small proportion of the total number of species, which have appeared in past time, has been thus chronicled, yet, by collecting the broken fragments of the record, an outline at least of the history of life upon the earth can be deciphered.

It cannot be too frequently stated, nor too prominently kept in view, that, although gaps occur in the succession of organic remains as recorded in the rocks, there have been no such blank intervals in the

progress of plant and animal life upon the globe. The march of life has been unbroken, onward and upward. Geological history, therefore, if its records in the stratified formations were perfect, ought to show a blending and gradation of epoch with epoch, so that no sharp divisions of its events could be made. But the record of the history has been constantly interrupted: now by upheaval, now by volcanic outbursts, now by depression, now by protracted and extensive denudation. These interruptions serve as natural divisions in the chronicle, and enable the geologist to arrange his history into periods. As the order of succession among stratified rocks was first made out in Europe, and as many of the gaps in that succession were found to be widespread over the European area, the divisions which experience established for that portion of the globe came to be regarded as typical, and the names adopted for them were applied to the rocks of other and far distant regions. This application has brought out the fact that some of the most marked geological breaks in Europe do not exist elsewhere, and, on the other hand, that some portions of the record are much more complete there than in other regions. Hence, while the general similarity of succession may remain, different subdivisions and nomenclature are required as we pass from continent to continent.

It will thus be understood why considerable diversity of opinion has existed and still continues as to the terms to be applied to the stratigraphical series in the earth's crust and as to the equivalence of the subdivisions of this series in different parts of the world. Efforts have from time to time been made with more or less success to devise some commonly applicable and generally acceptable system of classification and nomenclature. Allowance must be made for the peculiarities and usages of different languages, a term not having always the same meaning in different countries. But it is certainly desirable that, as far as possible, not only stratigraphical but all other terms generally used in scientific writings should everywhere be employed in precisely the same sense, and that a unification of nomenclature should be adopted.[1]

[1] The International Geological Congress has, since 1881, laboured strenuously to effect some reform in this matter, but only with partial success. The scheme adopted at the last meeting (Paris, 1900) comprised the following stratigraphical subdivisions. 1st Order: Eras of time, represented by Groups of strata, Palæozoic, Mesozoic, Cainozoic. 2nd Order: Periods of time, represented by Systems of strata, as in the four great Palæozoic systems. 3rd Order: Epochs of time, represented by Series of strata. 4th Order: Ages of time, represented by Stages of strata. 5th Order: Phases of time, represented by Zones of strata. Various modifications are likewise made in the customary terminations in order to conform with this scheme. Thus the divisions of the second order are all made to terminate in *ique*. The familiar Cambrian, Silurian, and Devonian become Cambrique, Silurique, and Devonique, or Cambric, Siluric, Devonic, as they would be written in English. The divisions of the fourth order are meant all to end in *en* (*an* in English), as Bartonian, Portlandian, &c. It is obvious, however, that differences of opinion must arise as to the division into which a particular section of strata should be classed, whether, for instance, if should go into the third order or the second order. Whether such an artificial precision of terminology is desirable may be open to question, and it may be doubted whether the recommendations of any congress, international or other, will be powerful enough to alter the established usages of a language. The chrono-

The smallest subdivisions of the Geological Record are laminæ, a number of which may make a stratum, seam, or bed. As a rule a stratum is distinguishable by lithological rather than palæontological features. Where one, or a limited number of beds, is characterised by one or more distinctive fossils, it is termed a Zone or Horizon, and, as already mentioned, is often known by the name of a typical fossil, as the different zones in the Cretaceous system are by their special species of cephalopods, brachiopods, or echinids, those in the Lias by their ammonites, and those in the Silurian system by their graptolites.[1] Two or more such zones, united by the occurrence in them of a number of the same characteristic species or genera, may be called Beds or an Assise, as in the "Micraster beds or assise" of the Cretaceous system, which include the zones of *M. cortestudinarium* and *M. cor-anguinum*. Two or more sets of such connected beds or assises may be termed a Group or Stage (*étage*). In some cases, where the number of assises in a stage is large, they are grouped into sub-stages (*sous-étages*) or sub-groups. Each sub-stage or sub-group will then consist of several assises, and the stage or group of several sub-stages or sub-groups. A number of groups or stages constitute a Series, Section (*Abtheilung*), or Formation, and a number of series, sections, or formations may be united into a System.[2]

The nomenclature adopted for these subdivisions bears witness to the rapid growth of geology. It is a patchwork in which no uniform system or language has been adhered to, but where the influences by which the progress of the science has been moulded may be distinctly traced. Some of the earliest names are lithological, and remind us of the fact that mineralogy and petrography preceded geology in the order

logical terms *Era*, *Period*, *Epoch* and *Age* have been habitually used by English writers as almost equivalent, or at least interchangeable, while the term *Group* has been so universally employed in our literature for a division subordinate in value to *Series* and *System* that the attempt to alter its significance would introduce far more confusion than can possibly arise from its retention in the accustomed sense.

The student who may wish to pursue this subject may consult the various *Compt. rend. Congrès. Géol. Internat.* since 1881; and the following papers: Professors Meunier Chalmas and De Lapparent, "Note sur la Nomenclature des Terrains Sédimentaires," *B. S. G. F.* xxi. (1893), p. 438; "A Symposium on the Classification and Nomenclature of Geologic Time-divisions," by J. Le Conte, G. K. Gilbert, W. B. Clark, S. W. Williston, Baily Willis, C. R. Keyes and S. Calvin, *Journ. Geol.* vi. (1898), pp. 333-355; T. C. Chamberlin. "The Ulterior basis of Time-divisions and the Classification of Geologic History," *op. cit.* pp. 449-462; H. S. Williams, "The Classification of Stratified Rocks," *op. cit.* p. 671; B. Willis, "Individuals of Stratigraphic Classification," *op. cit.* ix. p. 557.

[1] Professor Gaudry estimates the total number of zones in the European geological series at 114. In this calculation the Jurassic system is allowed no fewer than 34; the Carboniferous and Permian together, 10; and the Cambrian and Silurian together, 20 ('Enchaînements du Monde Animal: Fossiles Primaires,' 1883). Professor Lapworth has recognised 20 distinct graptolite zones in the Cambrian and Silurian systems (*Ann. Mag. Nat. Hist.* ser. 5, vols. iii. iv. v. vi. (1879-80), see especially the last part of his paper in vol. vi. p. 196 *seq.*). See also H. B. Woodward, "On Geological Zones," *Proc. Geol. Assoc.* xii. (1892), p. 295; J. E. Marr, "Principles of Stratigraphical Geology," 1899, p. 68; A. J. Jukes-Browne, *Geol. Mag.* 1899, p. 216.

[2] Compare Hébert, *Ann. Sci. Géol.* xi. (1881).

THE GEOLOGICAL RECORD,

OR, ORDER OF SUCCESSION OF THE STRATIFIED FORMATIONS OF THE EARTH'S CRUST.

(To face page 860.)

	Europe.	North America.			India and adjacent regions.	Australasia.
Quaternary or Post-Tertiary.	**Post-Glacial or Human Period** (p. 1347). Historic.—Up to the Present Time. Prehistoric. { Iron, Bronze, and later Stone Ages. Neolithic; alluvium, peat-mosses, lake-dwellings, &c. Palæolithic; river-gravels, caves, &c.	Generally similar to the European series, but with fewer proofs of the presence of man.			Recent alluvia, &c.	Recent alluvia, ossiferous caverns, sand-dunes, shell-mounds, &c.
	Pleistocene or Glacial (Diluvium) (p. 1301). Cave deposits, Loess, older valley-gravels. Raised beaches, latest moraines. Upper Boulder-clay, esker drifts. Interglacial deposits. Lower Boulder-clay or Till.	Stratigraphical series like that of Europe. The abundant marine, lacustrine, and fluviatile terraces in the upper part of the series have been comprised in the Champlain Group. They overlie unstratified drifts with true boulder-clay at the base.			Large moraines far below present limits of the Himalayan glaciers. Deposits of laterite.	Ancient gravels and terraces. Oldest moraines of New Zealand, extending below present sea-level. Traces of moraines among the Australian Alps and in Tasmania.
		Atlantic Border.	Interior.	Pacific Border.		
Tertiary or Cainozoic.	**Pliocene** (p. 1275). Newer, including the English Forest-bed Group, Norwich and Red Crag; the Scaldesian Group of Belgium, the Arnusian (Sicilian) and Astian of France and Italy. Older, comprising the Lenham Beds and Coralline Crag of England, Diestian of Belgium, Plaisancian of southern France and Italy.	Marine Floridian series consisting of— 3. Lafayette Group and Lagrange Beds. 2. De Soto, Croatan. 1. Caloosahatchie, Waccamaw.	Subaerial and lacustrine series, comprising the— Blanco Stage. Palo Duro or Goodnight, and perhaps upper part of Loup Fork.	Thick marine series of San Francisco (Lake Merced).	Siwalik Group of the Punjab. Upper Manchhar Beds of Sind.	Fluviatile terraces and basalt-sheets of New South Wales. Wanganui Series of New Zealand, with 70 to 90 per cent of living species of mollusks.
	Miocene (p. 1261). Not known in Britain. In France, Switzerland, and Italy the following subdivisions have been made:— 3. Tortonian (Œningen, upper fresh-water molasse, and Brown Coal). 2. Helvetian (Upper Marine Molasse). 1. Langhian (Burdigalian, Mayencian, Lower fresh-water Molasse). Above these subdivisions some writers have added (4) Sarmatian and (5) Pontian.	Marine formations, subdivided into— 3. Yorktown or Chesapeake. 2. Chipola. 1. Chattahoochee.	Lacustrine deposits classed as Loup Fork (Nebraska) substage. Deep River substage. John Day Group.	Ione, Tuscan, and Astoria Groups.	Lower part of Manchhar Group of Sind. Gaj Group with marine fossils.	In Victoria, marine sands and limestones, lacustrine clays and lignites, fluviatile auriferous gravels buried under sheets of basalt. In New Zealand, marine, calcareous, and argillaceous strata in the east and central part of North Island, and both sides of South Island. Pareora series of Capt. Hutton.
	Oligocene (p. 1246). In Britain, the "Fluvio-marine series" of Isle of Wight, also the basalt plateaux of Antrim, Inner Hebrides, Faroe Islands, Iceland, Greenland. In France, Belgium, Switzerland, and Italy the following subdivisions are recognised:— 3. Aquitanian (marine marls of Hanover, &c., Brown Coal of Lower Rhine). 2. Stampian (Rupelian, Septaria-clay of North Germany). 1. Tongrian (Sannoisian, Upper Flysch. Sestian, Egeln marine beds, Lower Brown Coal).	Not definitely recognised.	Fresh-water formations known as White River series, subdivided into three groups— 3. Protoceras Beds. 2. Oreodon Beds. 1. Titanotherium Beds.	Marine deposits of N. W. Oregon, overlying the Tejon series.		In Victoria, perhaps the older part of the series of marine deposits, consisting of clays with septarian nodules and abundant fossils. In New Zealand, the Oamaru series of Capt. Hutton.

	Europe.	North America. Atlantic Border.	North America. Interior.	North America. Pacific Border.	India and adjacent regions.	Australasia.
Tertiary or Cainozoic.	**Eocene** (p. 1223). Upper. Headon Hill or Barton Sands and Barton Clay of S. England. Ludian or Priabonian of N. France, including Paris gypsum and Bartonian limestones and Sables Moyens. Midd. Bracklesham beds and leaf-beds of southern England. Lutetian (Calcaire grossier and Caillasses of Paris basin). Lower. London Clay, Woolwich and Reading Beds, Thanet Sands of S. England. Londinian or Ypresian sands of Paris basin and Belgium. Sparnacian plastic clays and lignites. Thanetian limestones of Rilly, Sézanne, and sands of Bracheux. In southern Europe the prevalent sedimentary types are those of the Nummulitic Limestone and Flysch.	In the basin of the Potomac River the formations are— 2. Woodstock Group. 1. Aquia Creek Group. In Mississippi— 5. Vicksburg Beds. 4. Jackson Beds. 3. Claiborne ,, 2. Buhrstone. 1. Lignitic sands and clays with plants.	Fresh-water strata of great thickness, grouped as under— Upper. Uinta Group. Middle. Bridger ,, Lower. Wind River Group. Wasatch Group. Basal. Torrejon Group. Puerco Group.	Marine Tejon series of Oregon and California, with abundant tuffs and basalts.	The Nummulitic Limestone extends from southern Europe into India. In Sind the following Eocene groups are recognisable:— Nari, with nummulitic limestones in lower part. Kirthar, with massive nummulitic limestone. Ranikot, with gypsum and lignite and abundant marine fauna, including nummulites.	In N.S. Wales and Victoria, a lower series of lignitic and plant-bearing strata, underlying basalts and tuffs, is followed by marine deposits, which may be partly Eocene or even Cretaceous. In S. Australia and Victoria the basalt-sheets are underlain by marine clays and limestones, which attain a thickness of several hundred feet and have yielded an abundant fauna. In New Zealand the Oamaru deposits are underlain by argillaceous limestones, sandstones, and marls (Waipara series), regarded by the Geological Survey as Cretaceo-Tertiary and by Capt. Hutton as Cretaceous.
Mesozoic.	**Cretaceous** (p. 1161). Upper. Danian—Comprising the Pisolitic Limestone, Mons Limestone, Tuffeau de Ciply, &c. (Montian), and the Chalk of Faroe, Maestricht, &c. (Maestrichtian). Senonian—Comprising the Upper Chalk with flints, which in France has been subdivided into the following stages in descending order: (2) Aturian, comprising Dordonian and Campanian, and (1) Emscherian, with its substages of Santonian and Coniacian. Turonian—Middle Chalk with few flints, subdivided into (2) Angoumian and (1) Ligerian. Cenomanian—Lower Chalk, comprising the divisions of (2) Carentonian and (1) Rothomagian. Albian—Upper Greensand and Gault of England, with the zones of *Pecten asper*, *Schloenbachia rostrata*, and *Douvilleiceras mammillatum*. Lower. Aptian—Lower Greensand and part of Speeton Clay of England, with Gargasian and Bedoulian of Swiss Jura and France. Urgonian (Barremian)—Massive limestones (*Hippuritids*, &c.) of Orgon, valley of the Durance. Neocomian—Weald Clay, Hastings Sand, and part of Speeton Clay, Hauterivian marls and limestones of Switzerland and France, Valanginian limonite and limestone.	From New Jersey southward the formations are marine, and are divided into— 4. Manasquan. 3. Rancocas. 2. Monmouth. 1. Matawan. In Texas the subdivisions are— 6. Laramie, with lignites. 5. Glauconite Beds. 4. Ponderosa marls. 3. Austin Limestone. 2. Eagle Ford. 1. Timber Creek. From Long Island to Virginia, the Potomac formation with terrestrial flora. In Texas and Mexico, marine deposits grouped as— 3. Washita. 2. Fredericksburg. 1. Trinity.	7. Livingstone, largely volcanic, with land-plants. 6. Laramie (Lignitic), with many coal seams and a rich terrestrial flora; some marine fossils. 5. Montana, lacustrine and brackish water, subdivided into— (*b*) Fox Hills. (*a*) Fort Pierre. 4. Colorado, with a large marine fauna and some coal-seams. 3. Niobrara, marine marls and limestones, with Mosasaurs, &c. 2. Benton, shales, clays, and limestones, with marine, brackish-water, lacustrine, and terrestrial mollusks. 1. Dakota, sandstones, coals, lignites, and plants.	The enormously developed marine Shasta-Chico series of California, divided into— 3. Chico. 2. Horsetown. 1. Knoxville. The Cretaceous formations are prolonged northwards into the British possessions, where they include both marine strata and coal-seams.	The great basalt-plateau of Deccan— 3. Ariyalur Group with *Nautilus danicus* = Danian. 2. Trichinopoli Group = Turonian of Europe. 1. Utatur Group, probably equivalent to European Cenomanian.	In Queensland the Upper Cretaceous series is represented by the Desert Sandstone, with land-plants and marine shells; the Lower by the marine Rolling Downs formation. In New Zealand the Cretaceous system is represented by a thick series of sediments, some of which contain characteristic Cretaceous genera of shells, while others include seams of coal and abundant terrestrial plants, including dicotyledons.

SECONDARY OR	**Jurassic** (p. 1111). Purbeckian — Purbeck Beds of England, Serpulit and Münder Mergel of N.W. Germany. Portlandian — Portland Stone and Sands of England, Bononian of N.W. France, Tithonian of S. France. Kimmeridgian—Kimmeridge Clay of England, comprising (*b*) Virgulian, and (*a*) Pterocerian of central and northern France. Corallian—Coral Rag, Coralline Oolite, and Calcareous Grit. The upper half of this group is named in France Sequanian, and includes the two substages (*b*) Upper or Astartian, and (*a*) Lower or Rauracian. Oxfordian—Oxford Clay and Kellaways Rock. In France the lower part of the equivalents of the English Corallian group and the Oxford Clay and Kellaways Rock are grouped into (*d*) Upper Oxfordian or Argovian, (*c*) Lower Oxfordian or Neuvizyan, (*b*) Upper Callovian (Divesian), (*a*) Lower Callovian. Bathonian — Cornbrash, Forest Marble, Great or Bath Oolite. Fullonian—Fuller's Earth. Bajocian—Inferior Oolite. Lias. { Upper Lias—Toarcian of France. Middle Lias — (Marlstone); Charmouthian of France, which includes also the upper part of Lower Lias. Lower Lias—Sinemurian and Hettangian.	No marine strata hitherto found. The lower part of the Potomac formation may be Jurassic.	Above the marine platform mentioned below lie the groups in Wyoming and Colorado named by Marsh— (*b*) Atlantosaurus Beds. (*a*) Baptanodon Beds. Lower Jurassic marine fossils occur in Wyoming, Dakota, and other States.	Middle and Lower Jurassic deposits have been detected in California, Oregon, and among the islands within the Arctic circle.	Marine Jurassic formations are best developed in Cutch, where they are arranged as under— 4. Umia group = Portlandian and Tithonian of Europe. 3. Katrol group, equivalent to part of Oxfordian and Kimeridgian. 2. Chari = Callovian and part of Oxfordian. 1. Patcham = Bathonian. The upper part of the great Gondwana formations is not improbably of Jurassic age.	In Queensland a series of strata, which may be of Jurassic age, has been subdivided as follows— (*b*) Ipswich Formation, with coals and a large terrestrial flora. (*a*) Burrum Formation, a great series of coal-bearing rocks. In New Zealand a thick series of sedimentary deposits is regarded as Jurassic. It includes both remains of terrestrial vegetation and marine shells (Ammonites, Belemnites, *Inoceramus*, &c.).
	Triassic (p. 1084). Lagoon facies (Germany, &c.). { Rhætic. { Keuper. { Muschelkalk. { Bunter. Pelagic facies (Alps, Mediterranean basin). Rhætic stage. Juvavian stage. Carinthian and Noric stages. Wetterstein Limestone and Alpine Muschelkalk. "Myophoria" Beds and Werfen group.	Red Sandstones of Connecticut, New York, New Brunswick, Nova Scotia, &c., forming the Newark series, with land-plants and Labyrinthodonts.	Red strata, with gypsum and rock-salt, between Wyoming and New Mexico.	In Idaho and the region thence to the Pacific coast representatives of the pelagic facies have been found, referable perhaps to the Juvavian, Carinthian, Noric, Dinarian, and Jakutian divisions.	Panchet group of Gondwana series, with land-plants, Labyrinthodonts, Dicynodonts, &c. Pelagic facies, well-developed in Himalaya region and Salt Range, including representatives of the following stages— Upper. { Sagenites Beds. Juvavian. Carinthian. Lower. { Anisian. Hydaspian. Jakutian. Brahmanian.	Hawkesbury series of N.S. Wales, subdivided into— 3. Wianamatta shales, ironstones, and coals. 2. Hawkesbury Sandstones. 1. Narrabeen Beds. In New Zealand a thick series of sediments grouped as— 3. Otapiri. 2. Wairoa. 1. Oreti.
PRIMARY OR PALÆOZOIC.	**Permian** (p. 1063). Zechstein Group or Thuringian. Rothliegendes Group or Saxonian. Lowest Group, which, where it presents a lagoon facies, is named Autunian, and where marine, Artinskian.	Upper Barren Measures of Pennsylvania, Prince Edward Island, Nova Scotia, and New Brunswick. In Kansas, Texas, and Nebraska, Permian formations contain an abundant marine fauna, and have been subdivided into three groups— 3. Marion of Kansas; Double Mountain of Texas. 2. Chase ,, Clear Fork ,, 1. Neosho ,, Wichita ,,			The great Gondwana system of mainly fluviatile strata probably represents the Upper Palæozoic and the Older and Middle Mesozoic formations of other countries. In the Salt Range marine limestones contain a mingling of Carboniferous and Permian species.	

Primary or Palæozoic.

Europe.	North America.	India and adjacent regions.	Australasia.
Carboniferous (p. 1014). Coal-measures (Stephanian, Uralian). Millstone Grit (together with Lower and Middle Coal-measures, comprised in the Westphalian and Moscovian subdivisions). Carboniferous Limestone series and Culm (Dinantian).	Upper. { Upper productive Coal-measures. Barren measures. Lower productive Coal-measures. Pottsville conglomerate. } Lower. { Mauch Chunk shales and sandstones. Pocono series. }	Productus beds of Salt Range. Talchir group of the Gondwana system.	New South Wales— 6. Newcastle Coal-measures. 5. Dempsey Beds. 4. Tomago Group. 3. Upper marine Group. 2. Greta Coal-measures. 1. Lower marine Series. Queensland— Bowen Formation — Upper, Middle, and Lower. Star Formation. Gympie Series.
Devonian (p. 980) and **Old Red Sandstone** (p. 999). Upper. { Famennian. Frasnian. } Upper Yellow and Red Sandstones, with *Holoptychius*. Middle. { Givetian. Eifelian. } Lower. { Coblenzian. Gedinnian. } Lower sandstones and flagstones, with *Psilophyton*, *Pterygotus*, *Cephalaspis*, &c., and great development of associated andesitic lavas and tuffs.	Upper. { Catskill Red Sandstone (Old Red Sandstone). Chemung Group. Genesee ,, } Middle. { Hamilton ,, Marcellus ,, } Lower. { Corniferous Limestone. } Upper Helderberg Onondaga ,, } Group. Oriskany Sandstone. }		In New South Wales a thick series of strata passing down into Silurian and upward into Carboniferous formations represents the Devonian system. In Victoria, Middle and perhaps Upper Devonian rocks are found.
Silurian (p. 933). Upper. { Ludlow Group. Wenlock ,, Llandovery ,, } Lower. { Caradoc or Bala Group. Llandeilo ,, Arenig ,, }	Upper. { Lower Helderberg Group. Water-lime. Niagara shale and limestone. Clinton Group. Medina ,, } Lower. { Cincinnati Group. Utica ,, Trenton ,, Chazy ,, Calciferous ,, }	Silurian fossils in northern Punjaub and Kashmir, north of Kumaun; central Himalayas of Hundes and Spiti.	In Victoria, Upper Silurian sandstones, limestones, and shales, with numerous fossils; Lower Silurian shales with successive graptolite zones. Both subdivisions of the system represented in Tasmania, and a thick mass of sediments in New Zealand is also referred to the system.
Cambrian (p. 908). Upper or Olenus Series. { Tremadoc Slates. Lingula Flags. } Middle or Paradoxides Series. { Menevian Group. } Lower or Olenellus Series. { Harlech and Llanberis Group and Olenellus zone. }	Upper or Potsdam, with Olenus and Dikelocephalus fauna. Middle or Acadian, with Paradoxides fauna. Lower or Georgian, with Olenellus fauna.	Neobolus or Khussak Beds of Salt Range with *Hoeferia* (akin to *Olenellus*), *Hyolithes*, &c.	Lower Cambrian of South Australia, and Cambrian of Tasmania.
Pre-Cambrian (Archæan) (p. 861). In Scotland— Dalradian metamorphosed sedimentary and igneous rocks. Torridonian sandstones, shales, and conglomerates. Lewisian gneiss. In Scandinavia— Seve group of arkose, sandstone, crystalline schists, and limestone. Dalarnian red sandstones, shales, and conglomerates. Urberget or fundamental gneiss.	Keweenawan—chiefly igneous rocks. Animikie—mainly sedimentary. Upper Huronian—quartzite, slates, chert, &c. Lower Huronian—green schists, quartzites, sandstones, limestones, conglomerates, &c. Coutchiching—quartz-schists and fine gneisses invaded by portions of the gneiss below. Laurentian—a complex mass of igneous rocks more or less gneissose.	Younger or peninsular gneiss. Older or Bundelkund gneiss.	Archæan rocks, believed to cover some 20,000 square miles in Australia, consisting of gneiss and various schists, quartzites, conglomerates, limestones, &c. In Tasmania, a large development of similar rocks. In New Zealand crystalline schists cover an area of 8000 square miles.

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of birth—Chalk, Oolite, Greensand, Millstone Grit. Others are topographical, and bear witness to the localities where the formations were first observed, or are typically developed—Oxfordian, Portlandian, Kimeridgian, Jurassic, Rhætic, Permian, Neocomian. Others are taken from local English provincial names, and remind us of the special debt we owe to William Smith, by whom so many of them were introduced into geological literature—Lias, Gault, Crag, Cornbrash. Others recognise an order of superposition as already established among formations—Old Red Sandstone, New Red Sandstone; while still another class is founded upon numerical considerations—Dyas, Trias. By common consent it is admitted that names taken from the region where a formation or group of rocks is typically developed, are best adapted for general use. Cambrian, Silurian, Devonian, Permian, Jurassic, are of this class, and have been adopted all over the globe.

But, whatever be the name chosen to designate a particular group of strata, it soon comes to be used as a chronological or homotaxial term, apart altogether from the lithological character of the strata to which it is applied. Thus we speak of the Chalk or Cretaceous system, and embrace, under that term, formations which may contain no chalk; and we may describe as Silurian, a series of strata utterly unlike in lithological characters to the formations in the typical Silurian country. In using these terms, we unconsciously adopt the idea of relative date. Hence such a word as Chalk, or Cretaceous, does not so much suggest to the geologist the group of strata so called, as the interval of geological history which these strata represent. He speaks of the Cretaceous, Jurassic, and Cambrian periods, and of the Cretaceous fauna, the Jurassic flora, the Cambrian trilobites, as if these adjectives denoted simply epochs of geological time.

The Geological Record is classified into five main divisions: (1) Pre-Cambrian, also called Archæan, Azoic (lifeless), Eozoic (dawn of life) or Proterozoic (earliest life); (2) Palæozoic (ancient life) or Primary; (3) Mesozoic (middle life) or Secondary; (4) Cainozoic (recent life) or Tertiary, and (5) Post-Tertiary or Quaternary. The Tertiary and Post-Tertiary are sometimes grouped together as Neozoic (new life). These divisions are further ranged in systems, each system in series, sections, or formations, each formation in groups or stages, and each group in single zones or horizons.[1] The accompanying generalised table exhibits the sequence of the chief sub-divisions.

PART I. PRE-CAMBRIAN.

§ i. General Characters.

In the classification of the materials of the earth's crust enunciated by Werner the term "Transition rocks" was applied to a large series of

[1] On the classification of the Geological Record see Professor Renevier, *Bull. Soc. Vaud.* xiii. p. 229; *Arch. Sci. Phys. Nat.* xii. (1884), p. 297; *Compt. rend. Congr. Géol. Internat.* 1894, pp. 523-695; F. Frech, *op. cit.* 1897, Memoires, p. 27; Dr. W. T. Blanford, *Geol. Mag.* 1884.

stratified formations, which, underlying the fossiliferous or what were then called "Secondary" deposits, and overlying the various crystalline masses which were regarded as the most ancient or "Primary" part of the earth's surface, were believed to record an intermediate period of terrestrial history, between the time when any such crystalline materials as granite were laid down from a supposed universal ocean and the time when ordinary sediment accumulated and entombed the remains of the earliest animal life. Long after the theoretical considerations that led to its adoption had been proved to be fallacious, this term "transition" continued to maintain its ground as the designation of the most ancient stratified rocks underlying the Old Red Sandstone, and containing the earliest known organic remains. The researches of Murchison and Sedgwick eventually showed that these venerable formations contained a well-marked succession of organic types, whereby, as in the case of the Secondary rocks, so admirably made out by William Smith, they could be grouped into separate systems and formations, and could be identified in all parts of the world. The terms Cambrian and Silurian (which will be explained in later pages) were proposed by these illustrious pioneers to denote the oldest known fossiliferous formations, and soon entirely supplanted the older names "transition" and "grauwacke." The Cambrian system, as now generally understood, includes the lowest series of Primary, or as they are now called, Palaeozoic deposits (see *postea*, p. 908).[1]

But it has been well established that, while in some regions the base of the Cambrian system is separated by a strong unconformability from all rocks of older date, in other tracts it can only be defined by an arbitrary line, beneath which lie other still more ancient sedimentary formations. In these primeval deposits there are records of denudation and deposition, of alternate sedimentation and terrestrial movements, of stupendous and prolonged volcanic activity, and of distinct though scanty proofs that plant and animal life had already appeared upon the face of the globe. So far as our knowledge yet goes, there are no means of ascertaining the synchronism or homotaxis of these formations in widely separated regions. Fossil evidence entirely fails here as a guide, and mere mineral characters are only reliable within comparatively limited areas. All that can for the present be attempted is to determine the true order of sequence, tectonic relations, and general structure of the several distinct formations in each

[1] Besides the contributions to the general discussion of the origin and constitution of crystalline schists cited on p. 785, the following works bearing on pre-Cambrian rocks may here be mentioned: Zirkel, 'Petrographie,' vol. iii. pp. 141-425; Gümbel, 'Geogn. Beschreib. Fichtelgebirge,' 1879; Rosenbusch, *Neues Jahrb.* 1889, ii. p. 81, *Mittheil. Badisch. Geol. Ladesanst.* iv. i. (1899), *Tschermak's Mittheil.* xi. (1890), p. 144, xii. (1891), p. 49; "Report of the Geological Survey on N.W. Highlands of Scotland," *Q. J. G. S.* xliv. (1888), p. 378; Michel-Lévy, *B. S. G. F.* vii. (1879) p. 857; Barrois, *Ann. Soc. Géol. Nord.* viii. (1881), xv. (1888); W. E. Logan, 'Geology of Canada'; papers by Pettersen, Dahll, Tornebohm, and others, some of which are cited on p. 898; by Dawson, Lawson, and others in the Reports of the Geological Survey of Canada; by Irving, Van Hise, Bayley, and others in the Annual Reports, Bulletins, and Monographs of the United States Geological Survey. Some of the more important of these contributions are cited on later pages.

country where they occur, without in the meantime any serious attempt at correlation.

It must further be observed that these oldest stratified rocks have very generally undergone more or less alteration during the numerous terrestrial disturbances of geological history. Lying as they do at the base of the stratified part of the earth's crust, they have shared in all the movements by which, during the lapse of geological time, the overlying fossiliferous rocks have been affected. Every intruded mass of igneous rock, every volcanic outburst, every agent of contact or of regional metamorphism had first to pass through them before it could reach the younger rocks above. Hence not only have they usually been dislocated and plicated, but they have been abundantly invaded by intrusive materials of all ages, and their internal structure has frequently been subjected to such mechanical stresses, with accompanying chemical and mineralogical readjustments of their component materials, that they have passed into the condition of schists. In this highly altered state they often cannot be distinguished from still more ancient schists, the true origin of which is not certainly known. In some regions, indeed, where the older sedimentary formations have been greatly disturbed, a gradation may be traced, as we have seen, from unmistakable Palæozoic or Mesozoic sediments with recognisable fossils into thoroughly crystalline and foliated schists. Sometimes this transition is doubtless due to an actual extensive metamorphism of the sedimentary rocks, and in these instances there may be no means of separating the schists of which the sedimentary origin is ascertainable from those where it is not. The whole may be Palæozoic or Mesozoic. In other cases, there seems reason to believe that the gradation is rather due to excessive plication, whereby far more ancient schists and Palæozoic or Mesozoic strata have been so compressed that they agree in direction of strike, and have been so folded that portions of the one series have been enclosed within the other, considerable general metamorphism having at the same time been superinduced upon the whole.

From underneath these oldest undoubtedly sedimentary accumulations there rises to the surface a remarkable assemblage of thoroughly crystalline rocks, which range from amorphous masses such as granite, syenite, diorite, and gabbro, through many varieties of coarse and fine foliated rocks to the most silky schists and phyllites, and which further vary in chemical composition from thoroughly acid materials (gneisses, granites, &c.) to basic or even what are called "ultra-basic" compounds (peridotites, talc-schists, serpentines). Though sometimes amorphous over considerable spaces, and then not to be distinguished from ordinary igneous eruptive masses, they for the most part present a more or less distinctly schistose or foliated structure, some of their most abundant and conspicuous members being gneisses, often so coarsely banded as to pass into granite. They are often termed the "Crystalline Schists" (pp. 244, 785).

Possessing characters which link them on the one hand, with stratified, on the other, with eruptive rocks, this great series presents a peculiar type of structure, with which are connected some of the most

perplexing problems of geology.[1] These rocks cover extensive areas of the surface of the continents, occurring usually wherever the oldest formations have been brought to light. But they everywhere pass under younger formations, so that their visible superficies is probably but a very small part of their total extent. In the northern regions of Europe and of North America, they spread over thousands of square miles, forming the tableland of Scandinavia and Finland, the Highlands of Scotland, various detached areas throughout Europe and a large part of Eastern Canada and Labrador. They commonly rise to the surface along the axes of great mountain-chains in all quarters of the globe. So persistent are they, that they probably everywhere underlie the stratified formations as a general foundation or platform.

The origin and geological age of the "Crystalline Schists" have given rise to much controversy. Some geologists believe these rocks to be portions of the early crust of the globe which consolidated from a molten condition (p. 870). Others have regarded them as original chemical deposits on the floor of a primeval ocean. Repudiating the exaggerated views of those who have sought by metamorphic (metasomatic) processes to derive the most utterly different rocks from each other (for example, limestone from gneiss and granite, granite and gneiss from limestone, talc from granite, &c.), these Neptunist writers have insisted that the crystalline schists, in common with many pyroxenic and hornblendic rocks (diabases, gabbros, diorites, &c.), as well as masses in which serpentine, talc, chlorite, and epidote are prevailing minerals, have been deposited "for the most part as chemically-formed sediments or precipitates, and that the subsequent changes have been simply molecular, or at most confined in certain cases to reactions between the mingled elements of the sediments, with the elimination of water and carbonic acid." To support this view, it is necessary to suppose that the rocks in question were formed during a period of the earth's history when the ocean had a considerably different relative proportion of mineral substances dissolved in its (then probably much warmer) waters; they are consequently assigned to a very early geological period, anterior indeed to what are usually termed the Palæozoic ages. It becomes further needful to discredit the belief that any gneiss or schist can belong to one of the later stages of the geological record, except doubtfully and merely locally. The more thorough-going advocates of the pristine, "azoic," or "eozoic," date, of the so-called "Metamorphic" or crystalline schists, have not hesitated to take this step.[2] Some have gone so far as to assert that, by mere mineral characters, the crystalline rocks of contemporaneous periods can be identified all over the world. They assume that in the supposed chemical precipitation, the same general order has been followed everywhere over the floor of the ocean. Consequently a few hand-specimens of the crystalline rocks of a country are enough in their eyes to determine the geological position of these formations. Other geologists, recognising

[1] For a summary of opinions regarding these rocks, see Zirkel, 'Lehrbuch,' vol. iii. pp. 141-184. The origin of schists by metamorphism has been discussed *ante*, p. 785.

[2] See Sterry Hunt's 'Chemical Essays,' p. 382 *seq.*

that the more crystalline members of the series of schists graduate into rocks that are much less crystalline, and even into what are recognisably of sedimentary origin, likewise that they include and pass into masses that were certainly eruptive, have come to regard the schists as a metamorphic series of sedimentary and igneous rocks owing their characteristic foliated structure to some subsequent action upon them.[1]

One of the chief causes of difficulty in discussing the history of these rocks has lain in the fact that the crystalline schists are, in the majority of cases, separated from all other geological formations by an abrupt hiatus.[2] Instead of passing into, they are commonly covered unconformably by these formations, before the deposition of which they had usually been enormously denuded (see, for example, Fig. 369). Hence, not only is there generally a want of continuity between the schists and younger formations, but the contrast between them, in regard to lithological characters and geotectonic structure, is often so exceedingly striking as naturally to suggest the idea that the schists must belong to a far earlier period than that of the oldest sedimentary formations of the ordinary type, and to a totally different order of physical conditions. Natural, however, as this conclusion may be, those who adopt it probably seldom realise to what an extent it rests upon mere assumption. Starting with the supposition that the crystalline schists are the result of geological operations that preceded the times when ordinary sedimentation began, it assumes that they belong to one or more great early geological periods. Yet all that can logically be asserted as to the age of these rocks is that they must be older than the oldest formations which overlie them. If in one region of the globe they appear from under Cretaceous, in another below Carboniferous, in a third below Silurian strata, their chronology is not more accurately definable from this relation than by saying they are respectively pre-Cretaceous, pre-Carboniferous, and pre-Silurian. They may all of course belong to the same period; but where they occur in detached and distant areas, there is as yet no method whereby their synchronism can be proved. To assert it is an assumption which, though in many cases irresistible, ought not to be received with the confidence of an established truth in geology.

No portion of the Geological Record has in recent years been more diligently studied than the Crystalline Schists, which, underlying the vast pile of fossiliferous systems, contain the earliest surviving chronicles of the history of the earth. But the problems presented by these rocks are so many and so difficult that comparatively little progress has been made

[1] For further discussion of the more probable theories on this subject, see p. 870. Jukes ('Student's Manual of Geology,' 3rd edit. (1872), p. 369), pointed out that igneous rocks have undergone metamorphism no less than the sedimentary formations among which they lie, and his views have been confirmed by more recent work. See Lehmann's volume cited on p. 785; Allport, *Q. J. G. S.* xxxii. (1876), p. 425; G. H. Williams, cited on p. 790. Abundant confirmation of Jukes' prognostications has been obtained among the crystalline schists of Ireland, which he had partially studied.

[2] Many continental geologists, however, believe that the foliation of the schists is usually parallel to the stratification of the immediately overlying sedimentary formations. See, for instance, the summary given by M. Michel Lévy, *B. S. G. F.* xvi. 1888, p. 102.

in the endeavour to group them into formations or systems comparable with those of the fossiliferous series, and to ascertain the stages of geological history of which they are the memorials. The obstacles to increase of knowledge on this subject arise from the complication and obscurity of the geotectonic relations of the rocks. We have as yet no satisfactory clue to their chronological sequence. The assumption that the banding and foliation of the oldest gneiss represent original stratification has been generally abandoned as quite untenable. Hence all the early attempts to make out a stratigraphical succession among these rocks and to estimate their thickness are now recognised to be without foundation. Even where some sequence can be determined in portions of the gneisses, as where one mass has clearly been injected into another, the rocks have undergone so many disturbances, and so many and serious alterations of their internal structure, that it is hardly ever possible to follow up the clue for more than a limited distance, and still less to base upon it any generalisation as to a generally applicable order of appearance. Nothing in the least degree analogous to the evidence of fossils among the sedimentary rocks is here available. Whether eventually a determinable sequence among the minerals of these ancient rocks may be ascertained remains still uncertain. If it could be shown that certain minerals, or groups of minerals, came into existence at particular stages in the formation of the crystalline schists, a key might be found to some of the most difficult parts of this branch of geological inquiry. But though such a sequence has often been claimed to exist, no satisfactory proof has yet been adduced that it has been asserted on more than mere local observation. Certainly no general law of mineral sequence in geological times has hitherto been established.[1]

Thus while it is often difficult or impossible to ascertain the original order of succession among the crystalline schists of a particular region, it is even more difficult to form a satisfactory judgment as to the stratigraphical relations of the schists of two detached regions. There is usually no common basis of comparison between them, except similarity of mineral character and structure. But as it can be shown that even in a single area the crystalline schists may sometimes represent the results of many successive operations continuing through a long series of geological periods, it is obvious that the task of correlating these rocks in distinct, and especially in widely separated areas must be beset with almost insuperable obstacles.

Though in many countries a complete break occurs between the lowest gneisses and the overlying Palaeozoic sedimentary formations, there are

[1] The late T. S. Hunt was one of the chief exponents of the view that the crystalline pre-Cambrian rocks were deposited as chemical sediments in a certain definite order, and that the rocks could be recognised by their mineral characters, and be thereby grouped in their proper order all over the world. See, for example, his essays on "The Taconic Question in Geology" and on "The Origin of the Crystalline Rocks" in vols. i. and ii. of the *Trans. Roy. Soc. Canada*. How completely this artificial system breaks down when tested by an appeal to the rocks in the field has been well shown by R. D. Irving, *7th Ann. Rep. U.S. G. S.* (1888), p. 383.

other regions in which these gneisses are intimately associated with schists, limestones, quartzites, and conglomerates. The real character of this association has been variously interpreted, but on any explanation, it shows that such gneisses cannot be older than certain crystalline masses which may be regarded as probably, if not certainly, of sedimentary origin. Hence, while the inference from one series of sections has been that the gneisses belong to an early condition of the cooling crust of the globe, from another series it has been in favour of these gneisses and their associated sedimentary materials having been formed after the crust was solidified, and after mechanical and chemical sediments had begun to be accumulated.

Taking the widest view of the whole series of pre-Palaeozoic rocks, with their vast piles of various sedimentary formations above, and their complex series of crystalline massive and schistose rocks below, we encounter a somewhat serious difficulty in the attempt to group the whole of this varied assemblage of mineral masses under some common generally applicable stratigraphical name. Such a name has usually been held to imply that the rocks which it designates belong to one well defined portion of the Geological Record. But this implication is one which every geologist who has worked among these ancient rocks would earnestly deprecate, for he has in some measure realised how vast, varied, and long-continued were the geological changes of which they are the memorials. These mutations include many transformations of the earth's surface, many disturbances of its crust, with enormous denudation and sedimentation, comparable with, if not greater than, those which in later ages were repeated again and again, even after the older fossiliferous formations were laid down. So similar have been the results that it is now difficult, or impossible, to discriminate between the more ancient and the more recent operations. To class all the crystalline schists and the great piles of sedimentary and igneous materials into which they seem to pass, by one general name, after the type of "Cambrian," "Silurian," or "Devonian," may be convenient, but in the present state of our knowledge is apt to lead to confusion, by placing together masses which may be of widely different geological ages and of wholly dissimilar origin. Various terms have been proposed for this complex assemblage of rocks, such as Primitive, Proterozoic, Azoic, Agnotozoic or Archean. But from the data adduced in Book IV. Part VIII. regarding regional metamorphism, the student will understand how full of uncertainty must be the geological age of many areas of crystalline schists. Mere lithological characters afford no perfectly reliable test of relative antiquity. To prove that any region of crystalline schists may be "Primitive," "Azoic," or "Archean" we must first find these rocks overlain by the oldest fossiliferous formations. Where no evidence of this kind is available, the use of precise terms, which are meant to denote a particular geological era, is undesirable. There seems good reason to believe that the asserted "Archean" age of many tracts of schistose and granitoid rocks rests on no better basis than mere supposition, and that as the study of regional metamorphism is extended, the so-called "Archean" areas will be proportionately contracted.[1]

[1] Dr. Barrois thus expresses himself on this subject: "A great number of the rocks con-

Several distinct systems of mineral masses can be shown in some regions to exist beneath the base of the Palaeozoic formations, differing so greatly in petrological characters, in tectonic relations, and probably also in mode of formation, that they cannot, without a very unnatural union, be arranged in one definite stratigraphical series. For the present it seems to me least objectionable to adopt some vague general term which nevertheless expresses the only homotaxial relation about which there can be no doubt. For this purpose the designation "pre-Cambrian," already in use, seems suitable. The rocks which I would embrace under this epithet may include a number of separate systems or formations which have little or nothing in common, save the fact that they are all older than the base of the Cambrian rocks. Until our knowledge of these ancient masses is much more extensive and precise than it is at present I think it would be of advantage to avoid the adoption of any general terminology which would involve assumptions as to their definite place and sequence in the geological record, their mode of origin, their relation to the history of plant and animal life, or their identification in different countries.

As an illustration of the danger of such assumptions, I may refer to the history of the investigation of the Laurentian rocks of Canada. From the early observations of Sir W. Logan and Mr. Alexander Murray these rocks came to be regarded as types of the oldest gneisses of the globe. They were looked upon as probably metamorphosed marine sediments that had formed the solid platform on which the whole series of fossiliferous systems of North America had been deposited. The name Laurentian applied to them was transferred to similar rock-masses in other parts of the globe, and came to be accepted as the designation of the oldest known zone in the crust of the earth. But eventually it was discovered by Mr. Lawson that some part, at least, of the Laurentian gneiss is essentially of igneous not of sedimentary origin, and is actually intrusive into what are undoubtedly sedimentary strata. It could not, therefore, itself as a whole be the oldest rock; and all the generalisations and identifications founded on its supposed position fell to the ground. The term Laurentian cannot henceforth have more than a local significance. It serves to designate certain ancient crystalline rocks of Canada, but a geologist would not now employ it to denote any of the rocks of another region, even though they might present similar general lithological characters. We must in the meanwhile be content to restrict the application of such names to the regions in which they originated. There will be much less impediment to the progress of investigation by the multiplication of local names than

sidered to be Archæan in Brittany are only metamorphosed Cambrian or Silurian rocks, having merely the facies of primitive rocks. We do not think that Brittany can be the only region where this is the case; on the contrary, it seems to us probable that the Palæozoic formations are destined to spread more and more over geological maps, at the expense of the 'primitive formations,' by assuming gneissic and schistose modifications" (*Ann. Soc. Géol. Nord.* xi. (1884), p. 139; *ante*, p. 781). Reusch's discovery of fossils in the mica-schists of Southern Norway proved some of the supposed "Archæan" rocks to be of Upper Silurian age (*postea*, pp. 899, 925, 970). Lower Silurian crinoids have been found in the supposed Archæan tract of Virginia (N. H. Darton, *Amer. Journ. Sci.* xliv. (1892), p. 50).

by the attempt to force identifications for which there is no satisfactory basis. Each country will have its own terminology for pre-Cambrian formations, until some way is discovered of correlating these formations in different parts of the globe.

Although where the stratigraphical succession is most complete the gneisses that rise from under the oldest sedimentary rocks have been found to pierce these rocks, and thus to be of later date; yet in most regions no such proof of posteriority is to be seen. The coarse banded gneisses are usually the foundations on which the stratified fossiliferous formations unconformably rest. There is thus an obvious advantage in treating these gneisses first in an account of pre-Cambrian rocks. I shall here follow this arrangement, and reserve for a later section a description of the sedimentary and igneous formations which intervene between the gneisses and the base of the Cambrian system.

1. *The lowest gneisses and schists.*

It has often been noticed that the oldest known crystalline rocks present a remarkable sameness of general mineral characters in all parts of the earth. Sedimentary formations constantly vary from country to country, but when we descend beneath their lowest members we come upon a wholly different group of rocks, which, like those of undoubtedly igneous origin, retain one general type of structure and composition. These rocks include massive materials such as granite, syenite, gabbro, diorite, and hornblende-rock. But even in these a tendency to a schistose arrangement can usually be observed. By far the most generally prevalent structure is a more or less definite foliation. The coarser varieties are marked by alternate bands of distinct mineral characters, orthoclase, plagioclase (commonly an acid variety), quartz, hornblende, and mica (white and black) being universally conspicuous. Such rudely foliated and coarsely-banded gneisses offer gradations into masses which cannot be distinguished from ordinary eruptive material. The banding is sometimes strongly marked by the separation of the more silicated from the less silicated minerals, as where layers of felspar or of quartz alternate with others of hornblende, pyroxene, or biotite.

While the foliation and the arrangement of the minerals in parallel bands give a bedded aspect to these rocks, the resemblance of this structure to the true bedding of detrital materials is more apparent than real. A little examination shows that the layers are not persistent, that they cross each other, and that portions of one may be entirely separated and enclosed within another. Even where there has been an original banding of the material, the rock has usually undergone enormous mechanical compression and deformation. It has been plicated, rolled out, dislocated, and crumpled again and again. Hence, though for short distances it is possible to separate out layers or bosses of felspathic, hornblendic, pyroxenic, peridotitic, or serpentinous composition from the general body of gneiss, the geologist who tries to fix definite stratigraphical horizons by this means soon abandons the attempt in despair, and comes to the

conclusion that no sequence of a trustworthy nature can be established in the body of the gneiss itself.

From the coarsest gneisses gradations may be traced to fine silky schists; and this not only on a large scale in tracts capable of being delineated on a map, but on so small a scale as to be illustrated even in hand-specimens. Such transitions seem to arise from the different effects of mechanical deformation on materials that offered considerable differences in lithological composition and structure. Fine talcose schists, for example, can be traced to original peridotites; hornblendic and actinolitic schists to such rocks as gabbro, diorite, or dolerite, and coarse granitoid gneisses to granite, syenite, and similar eruptive masses (pp. 428, 787).

In the older accounts of these rocks the gneisses are described as passing into or alternating with a wholly different type of rocks, among which may be included limestone (sometimes strongly graphitic), dolomite, quartzite, graphite-schist, mica-schist, and other varieties of schistose material. This apparent gradation was believed to mark an original transition of the sediment out of which the gneiss was thought to have been formed into the calcareous, argillaceous, or carbonaceous sediment, which was the earliest condition of the associated limestones and schists. It was thus looked upon as evidence that the whole crystalline series represented, in a metamorphosed state, an ancient accumulation of sedimentary materials. The existence even of organic remains in the limestone was insisted upon, and the so-called *Eozoon* was cited as the most ancient relic of animal life.[1] But there is now every reason to believe such gradations to be generally deceptive. As a result of the enormous mechanical compression and deformation which these ancient rocks have undergone, igneous and aqueous materials have been so plicated and crushed together, and have undergone such profound metamorphism, that it is sometimes hardly possible to trace a boundary between them. At the same time there seems no reason to look upon the limestones, argillites, quartzites, and schists as other than intensely altered sediments, which in theory, if not in actual practice on the ground, must be separated from the gneisses.

Allusion has already (p. 864) been made to various theories of the genesis of the lowest gneisses and schists. Of these theories only three deserve further notice here. (1) That these rocks are a portion of the original crust which solidified on the surface of the globe. (2) That they are ancient sedimentary rocks in a metamorphosed condition, and in some parts so changed as to have been actually melted and converted into intrusive material. (3) That they are essentially eruptive rocks, comparable with the deeper seated or plutonic portions of such igneous rocks as may be seen to traverse the earth's crust, but sometimes associated with metamorphosed sedimentary strata into which they have been intruded.

(1) From the ubiquity of their appearance, the persistence of their striking lithological characters, and especially the apparent blending in them of the igneous and sedimentary types of structure, the idea not unnaturally arose that the lowest crystalline rocks represent the first

[1] See on this subject *postea*, p. 878, and authorities there cited.

crust that formed on the earth.[1] These rocks have been supposed to include some of the early surfaces of consolidation of the molten globe, and some of the first sediments that were thrown down from the hot ocean which eventually condensed from the atmosphere. Such a speculative view of their origin may seem not incredible in regions where these ancient crystalline rocks are covered unconformably by the oldest Palæozoic formations, from which they are marked off by so striking a contrast of structure and composition, and to which they have contributed so vast an amount of detrital material. But it must be tested by the evidence of the rocks themselves, not only where the geological record is confessedly incomplete, but where it is comparatively full. Nowhere among the lowest gneisses is any structure observable which can be compared with the superficial portion of a lava that cooled at the surface. Nor have rocks been discovered among them that can be regarded as of the nature of volcanic tuffs and breccias. On the contrary, the analogies they furnish are with deep-seated and slowly-cooled sills and bosses. The supposed intercalation and alternation of limestone and other presumably sedimentary materials in the old gneisses are probably all deceptive. In some regions they can be shown to be so, and it can there be demonstrated that the gneisses are really eruptive rocks which pierce the adjacent sedimentary or schistose masses, and are thus of younger age than these. If this relation can be clearly established in regions where the evidence is fullest, it is obviously safe to infer that a similar relation might be discoverable if the geological record were more complete, even in those parts of the world where the break between the lowest gneisses and the Palæozoic formations seems to be most pronounced. At least the possibility that such may be the case should put us on our guard against adopting any crude speculation about the original crust of the earth.

The present condition of these ancient rocks differs much from that which they originally possessed. In particular they have undergone enormous mechanical deformation, have been to a large extent crushed and recrystallized, and have acquired a marked schistose structure. But in every large region where they are developed we may obtain evidence to connect them with plutonic intrusions, not with superficial consolidation, and to show that many of their essential details of structure may be paralleled among much later crystalline schists produced from the metamorphism of Palæozoic sediments and igneous rocks.

(2) That the lowest gneisses of Canada and other regions are metamorphosed sedimentary rocks was generally believed until not many years ago, on the grounds above stated (p. 864). But the increased attention which has been given to the study of the subject since Professor Lehmann's great work on the Saxon gneisses appeared in 1884, has led to so complete a revolution of opinion that this belief, at least as formulated by Sterry Hunt, is now generally abandoned. Those who still hold it in a modified

[1] See Credner's "Elemente," 9th edit., p. 369. Die Fundamentalformation; Erstarrungskruste. Compare also Rosenbusch, *Neues Jahrb.* 1889, ii. p. 81. J. Lomas, *Geol. Mag.* 1897, p. 537.

shape recognise that the original sediments must have differed considerably from those of any unquestionably sedimentary formation, and were probably deposited under peculiar conditions. They admit that these rocks have undergone extreme metamorphism, and that the alteration of them has been carried so far as to reduce them in some places to an amorphous crystalline condition which cannot be distinguished from that of normal eruptive material. It has been maintained, indeed, that the Laurentian gneisses of Canada have been produced by the actual fusion of the older sedimentary pre-Cambrian formations and the absorption of these rocks into the general magma of eruptive material which now appears as gneiss.[1] The intrusive character of some of the gneiss, which might be regarded as proof of its really igneous origin, is accounted for by what is called an "aquo-igneous fusion" of some parts of the sedimentary rocks, and their intrusion into less completely metamorphosed portions of the series.

(3) Probably the great majority of geologists now adopt in some form the third opinion, that the oldest or so-called "Archæan" gneisses are essentially eruptive rocks, and that they should be compared with the larger and more deeply-seated bosses of intrusive material now visible on the earth's surface. Whether they were portions of an original molten magma protruded from beneath the crust, or were produced by a refusion of already solidified parts of that crust or of ancient sedimentary accumulations laid down upon it, must be matter of speculation. In the gathering of actual fact we cannot go beyond their character as eruptive rocks, which is the earliest condition to which they can be traced, and we must consequently place them in the same great series as all the later eruptive materials with which geology has to deal. It is quite true that they have been profoundly modified since their original extrusion, but traces of their original character as masses of mobile, slowly crystallizing and segregating material have not been entirely effaced.

Looking at the gneisses as a whole, with their various accompaniments, we find them to form a complex assemblage of crystalline rocks which, though generally presenting a foliated structure, pass occasionally into the amorphous condition of ordinary eruptive rocks. In composition they range from granite at the one end to peridotites and serpentines at the other. Hand-specimens of these rocks in their amorphous or unfoliated condition do not differ in any essential feature from the material of ordinary intrusive bosses in later portions of the terrestrial crust, and the same similarity of structure is borne out when thin slices are placed under the microscope.

The most convincing proofs of the really eruptive nature of the gneisses are to be found in those tracts where they have undergone least disturbance, and where therefore the way in which they traverse the adjacent rocks can be distinctly perceived. They are there seen to cross many successive zones of sedimentary material, to send out veins and protrusions, and to enclose portions of the adjacent rocks, while at the same time the surrounding masses present many of the familiar features of contact-metamorphism. Sections where these phenomena

[1] A. C. Lawson, *Annual Report Canadian Geol. Surv.* 1887.

can be satisfactorily observed are no doubt comparatively rare, for in general the rocks have been so crushed and recrystallized that their original relations have been destroyed. It is in consequence of these subsequent movements that so much difficulty has been found in determining the igneous nature of the gneisses and their intrusive character with reference to the rocks adjacent to them. The abundant veins which, as in ordinary granite bosses, proceeded from the original gneiss have been compressed into long parallel bands which seem to alternate with the schists among which they were injected, while portions of the surrounding rock enclosed within the gneiss have had a foliation superinduced upon them parallel to that of these bands. Any one who first studied the older rocks where such structures are visible might easily be deceived into the belief that these alternations of parallel strips of gneiss and schist, or gneiss and limestone, really represent a continuous sequence of sedimentary material. Nor would he readily perceive his mistake until he could trace the junction-line into some tract where, by cessation of the deformation, the original relation of the two groups of rocks could be observed.[1]

It is not difficult to obtain conclusive proof that in the complex assemblage of rocks constituting the lowest gneiss there are not only differences of composition and structure, but also differences of relative age. Some portions of the series can be distinctly seen to have been intruded into others. True dykes can be traced among them, both of acid and basic composition. In the north-west of Scotland, for example, the general body of gneiss is traversed by a multiplicity of dykes, cutting across the oldest foliation of the gneiss in a general north-westerly direction (Fig. 364). A detailed study of such an area reveals the fact that the fundamental rocks represent a prolonged series of igneous protrusions. As this complicated mass of eruptive material has subsequently undergone profound alteration by dynamo-metamorphism, the difficulties in unravelling its history need cause no surprise.

Leaving out of account the dykes which undoubtedly mark later injections of igneous material, and confining our attention to the general mass of gneiss in its variations from an amorphous or granitoid condition through the coarse banded varieties to the finer schistose types, we may pursue the history of these puzzling rocks by comparing them with the larger intrusive bosses and sills that have accompanied the volcanic eruptions of all geological periods. In deep-seated and slowly cooled masses of igneous material, as has already been pointed out (pp. 232, 711). we may frequently observe evidence of the segregation of the component minerals in bands or irregular patches. Such a segregation seems to have taken place sometimes after the erupted rock had come to rest, sometimes while it was still in movement. In the latter case the layers of separated materials have been dragged forward, so as not only to acquire a banded or streaky structure, but, as in the Tertiary banded gabbro of Skye, a crumpled and plicated arrangement, strongly resembling that of some ancient gneisses. How far the characteristic arrangements of the

[1] See A. C. Lawson, *Bull. Geol. Soc. Amer.* i. (1890), p. 184.

minerals in the coarse-banded gneisses may have arisen from a process of this kind in the consolidation of originally eruptive materials, remains still an open question, though the progress of research favours the idea that such has really been to a large extent their source.[1]

It is certain, however, that, besides this original banded structure, the gneisses, as the result of much mechanical deformation, have had other and later structures superinduced upon them, sometimes at successive periods of disturbance. The most massive granitoid rocks have thus been crushed down under great strain, and have recrystallized as fine granulitic gneiss or mica-schist. Epidiorites and amphibolites have by a similar process been converted into hornblende-schists. In these cases the reconstructed rocks usually exhibit a finely schistose structure quite distinct from that of the parent mass, but with no markedly banded arrangement. Occasionally, however, in the recrystallization of the materials, segregation into more or less definite layers or centres has come into play, so that in this obviously secondary arrangement a certain resemblance may be traced, though on a small scale, to the much coarser bands in the earliest remaining condition of the oldest gneisses.

There is yet another source of difficulty in judging of the relative age and origin of various structures among the crystalline schists. We have seen (p. 728) that granite, besides breaking through the old rocks and forming huge bosses as well as abundant veins among them, has sometimes been introduced into their substance in such a way that they seem to be permeated by the granitic material, which, in minute layers and lenticles, quite uncrushed, may be traced between the foliation planes of granulitic gneisses and different schists. Where subsequent movement has crushed and drawn out such intercalated layers, younger gneiss is produced that simulates with extraordinary closeness some aspects of the most ancient and, so to say, original gneisses.[2] This transformation appears to take place even among schists that can be shown to have been originally sedimentary rocks. So that by a new pathway of inquiry we are brought once more to the old doctine of the cycle of change through which the materials of the earth's crust pass. The most ancient gneisses exposed to disintegration on the earth's surface have furnished materials for the formation of sedimentary deposits, which, after having been deeply buried within the earth's crust, crushed, plicated, and permeated with granitic material, present once more the aspect of the old gneisses from which they were in the first instance derived.

[1] This inference applies more particularly to the coarsely banded gneisses where the individual layers, consisting in great part of different minerals, resemble some of the segregation bands in eruptive masses (p. 256). There can be little doubt that, as already remarked, the efficacy of mechanical deformation as a factor in the production of gneisses has been pushed too far. It will account for the crushed granulitic and schistose condition, but hardly for the coarsely banded structure, where the layers consist of very different mineral aggregates. I have discussed this subject in the paper upon the banded structure of old gneisses and Tertiary gabbros cited on p. 256, and in the joint paper with Mr. Teall, referred to on the same page.

[2] See Mr. Horne's observations in *Geological Survey Report* for 1892, and his joint paper with Mr. Greenly, cited *ante*, p. 729.

It is only when the complex tectonic relations of the several masses composing the oldest crystalline rocks are closely studied that we can adequately realise how hopeless would be the attempt to establish anything of the nature of a stratigraphical sequence among them. Where different eruptive materials present proofs of successive intrusion, we have indeed a clue to their relative age; but such evidence carries us but a small way. The gneisses where obviously intrusive are indisputably of eruptive origin, but they alternate with finely schistose bands which sometimes seem to cut them. The bedding or banding of the rocks affords no guide whatever as to sequence. It has been so folded and crumpled that even if it represented original stratification it could probably never be unravelled. But there is every reason to believe that it bears no real analogy to stratification. It may sometimes represent, as already stated, layers of segregation and flow-structure in an original igneous magma, at other times planes of movement in the crushing of already consolidated material. But whatever may have been its origin, it remains now in an inextricable complexity. Here and there, indeed, for short distances some well-marked band of rock may be traced, but the various rock-masses generally succeed each other in so rapid and tumultuous a manner as to defy the efforts of the field-geologist who would patiently map them.

As a rule, only where the earliest type of gneiss has been invaded by subsequently intruded masses can a successful attempt be made to disentangle the confused structure. Successive systems of dykes may thus be traced, and evidence may be obtained that powerful dynamic stresses affected the rocks between some of these intrusions. The dykes have sometimes been crushed, plicated, and disrupted until they have been reduced to isolated patches of schist irregularly distributed among the reconstructured gneiss. And through these involved and complicated masses newer groups of dykes have risen, to be again subjected to mechanical deformation (pp. 882-890).

The question may occur to the student whether this complex system of evidently plutonic igneous rocks was ever connected with any superficial volcanic activity. No such connection has yet been definitely ascertained, but it may be regarded as highly probable. If the most ancient gneisses with their dykes and bosses were the deep seated portions of the successive uprisings of the igneous magma which culminated in volcanic eruptions, we may hope eventually to discover some trace of the materials that were thrown out to the surface and accumulated there. In some of the overlying pre-Cambrian masses of sedimentary rocks abundant lavas, tuffs, and agglomerates have been found, indicating the outpouring of volcanic material at the surface during the deposition of these sediments (p. 891). The vast scale of some of these volcanic eruptions may be inferred from the fact that in the Lake Superior region the accumulated materials discharged at the surface attained a thickness which has been estimated at more than six and a half miles. It may be eventually discovered that some of these superficial manifestations of volcanic action have been connected with bosses, sills, or dykes that form part of the body of the gneiss below.

It must be confessed that much detailed work among the lower gneisses in all parts of the world is needed before the many problems which they present are solved. But the following conclusions regarding them may now be regarded as established: these rocks are in the main various forms of original eruptive material, ranging from highly acid to highly basic; they form in general a complex mass belonging to successive periods of extrusion; some of their coarser structures are probably due to a process of segregation in still fluid or mobile, probably molten, material consolidating below the surface; their granulitized and schistose characters, and their folded and crumpled structures point to subsequent intense crushing and deformation; their apparent alternations with limestone and other rocks which are probably of sedimentary origin, are deceptive, indicating no real continuity of formation, but pointing to the intrusive nature of the gneiss.

2. *Pre-Cambrian sedimentary and volcanic groups.*

In different parts of the world enormous masses of rocks are now known to intervene between the oldest or "Archæan" gneisses, and the bottom of the fossiliferous series of formations. It was in Canada that these rocks were first studied. Logan and Murray grouped them under the general name of Huronian, and they were believed to fill up the gap between the Laurentian gneiss on the one hand and the Potsdam sandstone or base of the fossiliferous series on the other. Later more detailed study of these rocks in Canada and the adjoining regions of the United States has shown them to possess even a greater importance than their original discoverers imagined, for they have been found to consist of several distinct groups or systems, attaining a vast thickness and presenting a record of stupendous disturbances, denudations and depositions of sediment, together with memorials of extensive and prolonged volcanic action. In the higher members of these sedimentary deposits, distinct remains of animal life have in several regions been found. There is thus opened out the possibility of the ultimate discovery of a series of fossiliferous formations even below the base of the Palæozoic systems.

Where metamorphism has not interfered with the recognition of their original characters, these ancient sedimentary rocks present no structural feature to distinguish them from the detrital accumulations of higher parts of the geological record. They consist of clays and muds hardened into shales and slates, of sand compacted into sandstones and quartzites, of gravels and shingles solidified into conglomerates. These rocks prove beyond question that the processes of denudation and deposition were already in full operation with results exactly comparable to those of Palæozoic and later time.

Few parts of the stratified crust of the earth present greater interest than these earliest remaining sediments. As the geologist lingers among them, fascinated by their antiquity and by the stubbornness with which they have shrouded their secrets from his anxious scrutiny, he can sometimes scarcely believe that they belong to so remote a part of the earth's history as they can be assuredly proved to do. The shales are often not

more venerable in appearance than those of Cambrian or Silurian time, and show as clearly as these do their alternations of finer and coarser sediment. The sandstones display their false-bedding as distinctly as any younger rock, and one can make out the shifting character of the currents and the prevalent direction from which they brought the sand. The conglomerates in their well-rounded fragments point as distinctly as the shingle of a modern beach to the waste of a land-surface and the pounding action of waves along the shore.

Not only are these structural details precisely similar to those of younger detrital rocks, but we may here and there detect the remains of the pre-Cambrian topography from which the primeval sediments were derived, and on which they were deposited. Hills and valleys, lines of cliff and crag, rocky slopes and undulating hollows have been revealed by the slow denudation of the pre-Cambrian strata under which these features were gradually buried. To this day so marvellously has this early land-surface been preserved under its mantle of sediment during the long course of geological time, that even yet we may trace its successive shore-lines as it gradually settled down beneath the waters in which its detritus gathered. We may follow its promontories and bays and mark how one by one they were finally submerged and entombed beneath their own waste.[1]

But these ancient stratified formations do not consist merely of clastic sediments. They include important masses of limestone and dolomite, sometimes highly crystalline, but elsewhere assuming much of the aspect of ordinary grey compact Paleozoic limestone. Sometimes they contain a considerable amount of graphite, and some of the shales are highly carbonaceous. In other places they are banded with layers and seams or nodules of chert, in a manner closely similar to that in which the Carboniferous Limestone of Western Europe contains its siliceous material. Sometimes the chert bands are as much as forty-five feet thick. The general character of these mingled carbonaceous, calcareous and siliceous masses at once reminds the observer of rocks which have undoubtedly been formed by the agency of organic life. Moreover there occur extensive deposits of iron-carbonate associated like the limestone with chert, and again recalling the results of the co-operation of plant and animal life. The large amount of carbon in some of the shales, points likewise in the same direction.

It must be confessed, however, that actual remains of recognisable organic forms have only been found in a few places below the *Olenellus*-zone or base of the Cambrian system, chiefly in North America. Traces more or less determinable of sponges, corals, echinoderms, brachiopods, gasteropods and merostomatous crustacea, with especially various forms of the family Hyolithidæ, indicate a low fauna somewhat like that of the Cambrian system above.[2] Dr. Barrois has followed a band of graphitic

[1] These features are admirably displayed in Ross-shire, N.W. Scotland, where the Lewisian gneiss, carved into hills and valleys, has been buried under the Torridon Sandstone, and has escaped destruction by the great displacements of the region (p. 890).

[2] G. F. Matthew, *Bull. Nat. Hist. Soc. New Brunswick*, ix. (1890), pp. 36, 42. C. D.

quartzite for a long way in the gneiss of Brittany, and has detected in it the presence of what may be radiolaria, belonging to their most primitive group, the Monosphæridæ.[1]

Reference may be made here to the controversy regarding the true nature of certain curious aggregates of calcite and serpentine, which were found many years ago in some of the limestones associated with the lower or Laurentian gneisses of Canada. These minerals were found to be arranged in alternate layers, the calcite forming the main framework of the substance, with the serpentine (sometimes loganite, pyroxene, &c.) disposed in thin, wavy, inconstant layers, as if filling up flattened cavities in the calcareous mass. So different from any ordinary mineral segregation with which he was acquainted did this arrangement appear to Logan, that he was led to regard the substance as probably of organic origin.[2] This opinion was adopted, and the structure of the supposed fossil was worked out in detail by Sir J. W. Dawson of Montreal,[3] who pronounced the organism to be the remains of a massive foraminifer which he called *Eozoon*, and which he believed must have grown in large thick sheets over the sea-bottom. The same view was likewise taken by Dr. W. B. Carpenter,[4] who, from additional and better specimens, described a system of internal canals having the characters of those in true foraminiferal structures. Other observers, however, notably Professors King and Rowney of Galway,[5] maintained that the "canal-system" is not of organic but mineral origin, having arisen in many cases "from the wasting action of carbonated solutions on clotules of 'flocculite' or, it may be, saponite—a disintegrated variety of serpentine, and in others from a similar action on crystalloids of malacolite. In both cases," according to Professor King, "there are produced residual 'figures of corrosion' or arborescent configurations, having often a regular disposition." The regularity of these forms was attributed by Messrs. King and Rowney to their having been determined by a mineral cleavage.[6] Pro-

Walcott, *10th Ann. Rep. U.S. G. S.* 1890, p. 552; "Pre-Cambrian Fossiliferous Formations," *B. Amer. Geol. Soc.* x. (1899), p. 199; *Congrès Géol. Internat.* Paris, 1900.

[1] *Compt. rend.* 8th August 1892. Sponges and foraminifera have also been reported from the pre-Cambrian rocks of Brittany (L. Cayeux, *Compt. rend.* June 1894, Feb. 1895; *B. S. G. F.* xxii. 1894, p. 197; *Ann. Soc. Geol. Nord.* xxiii. 1895, p. 52), but the organic nature of these supposed fossils has been disputed (H. Rauff, *Neues Jahrb.* 1893, ii. p. 57; 1896, i. p. 117).

[2] *Rep. Geol. Surv. Canada*, 1858; *Amer. Journ. Sci.* xxxvii. (1864), p. 272; *Q. J. G. S.* xxi. (1865), p. 45. Harrington's 'Life of Sir W. E. Logan,' 1883, pp. 365-378.

[3] *Q. J. G. S.* xxi. (1865), p. 51; xxiii. (1867), p. 257. See also his 'Acadian Geology,' 2nd edit.; 'Dawn of Life,' 1875; 'Notes on Specimens of Eozoon Canadense,' Montreal 1888, and "The Animal Nature of Eozoon," *Geol. Mag.* 1895.

[4] *Proc. Roy. Soc.* 1864, p. 545; *Q. J. G. S.* xxi. (1865), p. 59; xxii. (1866), p. 219. See also G. F. Matthew on "Eozoon and other Organisms," from St. John, New Brunswick. *Bull. Nat. Hist. Soc. New Brunswick*, ix. (1890), p.42.

[5] *Q. J. G. S.* xxii. (1866), p. 185.

[6] Professor W. King, *Geol. Mag.* 1883, p. 47. See the views of these writers, summarised in their work, 'An old Chapter in the Geological Record with a new Interpretation,' London, 1881, where a full bibliography will be found.

fessor Möbius of Kiel[1] also opposed the organic nature of *Eozoon*, maintaining that the supposed canals and passages are merely infiltration veinings of serpentine in the calcite. In some cases, however, the "canal-system" is not filled with serpentine but with dolomite, which seems to prove that the cavities must have existed before either dolomite or serpentine was introduced into the substance. It may be admitted that no structure precisely similar to that of some of the specimens of *Eozoon* has yet been discovered in the mineral kingdom.[2] But it must also be conceded that the chances against the occurrence of any organism in rocks of such antiquity, and which have been so disturbed and mineralised, are so great that nothing but the clearest evidence of a structure which cannot be other than organic should be admitted in proof. If any mineral structure could be appealed to, as so approximately similar as to make it possible that even the most characteristic forms of *Eozoon* might be due to some kind of mineral growth, the question would be most logically settled in a sense adverse to the organic nature of the substance.[3]

The opinion of the organic nature of *Eozoon* has been supposed to receive support from the large quantity of graphite found throughout the older rocks of Canada and the northern parts of the United States. This mineral occurs partly in veins, but chiefly disseminated in scales and laminæ in the limestones and as independent layers. Sir J. W. Dawson estimates the aggregate thickness of it in one band of limestone in the Ottawa district as not less than from 20 to 30 feet, and he thinks it is hardly an exaggeration to say that there is as much carbon in the "Laurentian" as in equivalent areas of the Carboniferous system. He compares some of the pure bands of graphite to beds of coal, and maintains that no other source for their origin can be imagined than the decomposition of carbon-dioxide by living plants.[4] The organic nature of all graphite, however,

[1] 'Palæontographica,' xxv. p. 175; *Nature*, xx. p. 272. See replies by Carpenter and Dawson, *Nature*, xx. p. 328; *Amer. Journ. Sci.* (3) xvii. p. 196; also *Amer. Journ. Sci.* (3) xviii. p. 117. A. G. Nathorst, *Neues. Jahrb.* 1892, i. p. 169.

[2] The nearest resemblance to the "canal-system" of *Eozoon* which I have seen in any undoubtedly mere mineral aggregate is in the structure known as micropegmatite, where, in the intergrowth of quartz and orthoclase, arborescent divergent tube-like ramifications of the one mineral are enclosed within the other (see Fig. 4). Mr. Rudler, who called my attention to the resemblance, showed me a remarkable micropegmatite, brought from the Desert of Sinai by Professor Hull, in which the Eozoonal arrangement is at once suggested.

[3] Whitney and Wadsworth in their 'Azoic System' (*Bull. Mus. Comp. Zool. Harvard*, 1884, pp. 528-548) give a summary of the controversy, and decide against the organic origin of *Eozoon*. From the zoological side also Römer and Zittel decline to receive Eozoon as an organism. In the pre-Cambrian rocks of Bohemia and Bavaria specimens were some years ago obtained showing a structure like that of the Canadian Eozoon. They were accordingly described as of organic origin, under the respective names of *Eozoon bohemicum* and *E. bavaricum*. But their true mineral nature appears to be now generally admitted. The original 'Tudor specimen' of Eozoon figured by Dawson has recently been re-examined by Prof. J. W. Gregory, who decides against its organic origin. *Q. J. G. S.* xlvii. (1891), p. 348.

[4] See Whitney and Wadsworth, 'Azoic System,' p. 539, and the suggestive paper by Dr. Weinschenk, *Zeitsch. Kryst. Min.* 1897; likewise the remarks made *ante*, p. 270, on the researches of M. Moissan on metallic carbides.

can hardly now be maintained. In Canada and the United States it not only occurs in the limestones, but in pegmatites and running in veins through the gneisses. So intimately does it penetrate some of these rocks as to suggest that it may have found its way in the form of gaseous or liquid hydrocarbons from some underlying magma.

An important and interesting feature of the pre-Cambrian sedimentary rocks is the occurrence among them of abundant proofs of extensive and prolonged volcanic action. Sheets of lava having an aggregate thickness of many thousand feet are interstratified with coarse and thick volcanic conglomerates and tuffs. The eruptive rocks include both basic and acid varieties, for among them are found diabase, melaphyre (often highly amygdaloidal), porphyrite, gabbro, quartzless and quartziferous porphyry, rhyolitic felsite, augite-syenite, and granite. Some further details regarding these masses will be given in subsequent pages. In the Lake Superior region the amygdaloidal diabases and the conglomerates are largely impregnated with native copper.

While in some regions the original characters of pre-Cambrian rocks, sedimentary and eruptive, are as easily determinable as those of any ordinary Palæozoic series, in others they have been more or less effaced by subsequent geological revolutions. Gradations can sometimes be traced, as in the Penokee district of Wisconsin, from greywackes and slates through stages of increasing metamorphism into mica-schists, which present every appearance of complete original crystallization.[1] The limestones have passed into the condition of marbles; the iron ores, probably originally carbonates, have become oxidised into limonite, hæmatite, and magnetite, while the ore has been concentrated into separate masses. The "greenstones" have passed into the condition of true schists.[2] Some of these metamorphosed areas present so many points of resemblance to the lower gneisses already described that it is not at all surprising that they should have been confounded, and that their true relations should only have been made out after much controversy and long-continued detailed study.

During the discussion as to the true relations of these pre-Cambrian stratified and eruptive rocks to the coarse-crystalline banded gneisses above described, it was pointed out that in some sections a complete and strong unconformability occurs between the two series. No doubt could there exist as to the enormous break that separates them. In other regions, however, the lower gneisses were shown to be so involved with schists, limestones and conglomerates that no satisfactory separation of them could be made, while in some places the gneiss actually crosses these rocks intrusively. Each country or district may present its own phase of the problem. At present, as already stated, no means exist for determining the true correlation of the pre-Cambrian rocks in separate, and especially in distant, areas. If we admit that the lowest gneisses with their accompaniments form an eruptive assemblage of which the component portions may belong to widely different periods of time, it is quite conceivable

[1] R. D. Irving and C. R. Van Hise, *10th Ann. Rep. U.S. G. S.* 1890, p. 434.

[2] G. H. Williams, *Bull. U.S. G. S.* No. 62, 1890.

that a certain group of sedimentary formations may be found in one district to lie unconformably on these gneisses, and in another to be pierced by some of their younger members.

There is likewise some difficulty in fixing the upper limit of the pre-Cambrian formations. Where the Cambrian rocks lie on them unconformably the obvious stratigraphical break forms a convenient line of division. But in some countries a thick mass of conformable sedimentary rocks underlies the *Olenellus*-zone which has been taken as the base of the Cambrian system, and in these instances the line of separation becomes entirely arbitrary. Sections of this nature are of great value, inasmuch as they impress upon the geologist that the artificial character of the divisions by which he classes the geological record is not confined to the fossiliferous formations, but marks also those of the pre-Cambrian series. Unconformabilities, even where wide-spread, cannot be regarded as universal phenomena,[1] and though of infinite service in classification, should be employed with the full consciousness that the blanks which they represent do not indicate any world-wide interruption of geological continuity, but may at any moment be filled up by the evidence of more complete sections.

With regard to the comparative value of the pre-Cambrian rocks in the chronology of geological history no precise statement can be made; but various circumstances show that they must represent an enormous period of time. We shall see in succeeding pages that from the general character of the Cambrian fauna it must be regarded as certain that life had existed on the earth for a long series of ages before that fauna appeared, in order that such well-advanced grades of organisation should then have been reached. One of the most interesting chapters of geological history would be supplied if some adequate account could be given of the stages of this long pre-Cambrian evolution.

Further, the mere thickness and variety of the pre-Cambrian formations, together with their unconformabilities and other structural features, suffice to prove that they represent an enormous chronological interval. In North America, where, so far as at présent known, they are most extensively developed, they are estimated to attain a thickness of more than 65,000 feet, or upwards of twelve miles, and have been regarded there as chronologically quite equal to the whole of the rest of the geological record. Even when we eliminate the bedded volcanic rocks from the computation and reduce the remaining sedimentary series to the lowest allowable dimensions, an enormous mass of stratified material remains, which, even if it had been uninterruptedly deposited, would have required a period of time comparable to probably more than that taken by the whole of the Palæozoic systems. But we know that the deposition was not continuous. Both in North America and in Europe there is clear evidence from marked unconformabilities that it was broken by epochs of upheaval and by long periods of extensive denudation. It is evident, therefore, that we must assign to the records of pre-Cambrian time a far more

[1] Mr. Van Hise has suggested that "some of the larger unconformities may be intercontinental in extent," *16th Ann. Rep. U.S. G. S.* (1896), p. 733.

important chronological value than has generally been apportioned to them.

If, as already stated, it is impossible in the present state of science to find any satisfactory basis for the correlation of the oldest gneisses in distant and disconnected regions, it is not more practicable to establish a basis of correlation for the pre-Cambrian stratified formations. The evidence of fossils hardly as yet exists, and mere lithological characters are in such circumstances of little value. All that can be done at present is to work out the succession of rocks in each well-defined geographical and geological area, giving local names to the stratigraphical groups or systems that may be established, and trusting to future research for some method of possibly ascertaining the parallelism of these divisions in different parts of the world. Hence in the following summary of the characters of the pre-Cambrian rocks in the Old World and in the New no general terminology will be attempted, but in each country the names and divisions adopted there will be given.

§ ii. Local Development.

Britain.—Much attention has been given in recent years to the pre-Cambrian rocks of the British Isles and a voluminous literature has arisen concerning them. Rocks, however, have been claimed as pre-Cambrian which are certainly eruptive masses of later date than parts of the Lower Silurian series. Others have been assigned to a similar position, though their relations to the older Palæozoic rocks cannot be seen, while others again cannot properly be disjoined from the lower portion of the Cambrian system. In the confusion which has thus been introduced it will be most satisfactory to restrict attention to those rocks and areas about the true relations of which there appears to be least room for dispute.

In no part of Europe are pre-Cambrian rocks better displayed than in N.W. Scotland, where, as already described (p. 792), they have undergone extensive regional metamorphism. Their position, previously indicated by Macculloch[1] and Hay Cunningham,[2] was first definitely established by Murchison,[3] who, with Nicol as his earlier colleague, showed that an ancient gneiss is unconformably overlain with a thick mass of dull red sandstones, above which lie (also unconformably, as was eventually discovered) quartzites and limestones containing fossils which he referred to the Lower Silurian system. He regarded the red sandstones as probably Cambrian, and after proposing the terms Fundamental and Lewisian for this underlying gneiss, he finally adopted instead of them the term Laurentian, believing the rocks to be the equivalent of those which had been studied and described by his friend Logan in Canada.[4] The

[1] 'A Description of the Western Islands of Scotland,' 1819.

[2] 'Geognostical Account of the County of Sutherland,' *Highland Soc. Trans.* viii. (1841), p. 73.

[3] *Brit. Assoc.* 1885, Sect. p. 85; 1857, Sect. p. 82; 1858, Sect. p. 94; *Q. J. G. S.* xiv. (1858), p. 501; xv. (1859), p. 353; xvi. (1860), p. 215; xvii. (1861), p. 171. Nicol, *Q. J. G. S.* xiii. (1857), p. 17; xvii. (1861), p. 85; *Brit. Assoc.* 1858, Sect. p. 96; 1859, Sect. p. 119.

[4] In the elucidation of the true relations of the rocks to each other in the N.W. of Scotland later geologists have taken part, more especially Dr. Hicks, Professor Bonney, Mr. Hudleston, Dr. Callaway, and above all, Professor Lapworth and the officers of the Geological Survey. The literature of the subject, up to 1888, will be found condensed in

subsequent discovery by the officers of the Geological Survey that the *Olenellus*-zone, or base of the Cambrian system, forms part of the series of quartzites, dolomites, and limestones,[1] proved these formations to be of Cambrian age. The quartzite at the bottom of the Cambrian series in the north-west of Scotland reposes with a strong unconformability, sometimes on the red sandstones, sometimes on the gneiss. Hence these last two distinct groups of rock were thus definitely proved to be pre-Cambrian. As they differ so strongly from each other, their respective limits can be easily followed, and as they extend over a united area of hundreds of square miles in the north-west of Scotland they afford abundant opportunities for the most detailed examination. The rocks of this region may be arranged in descending order as in the following table:—

Cambrian.		Dolomites and Limestones of Durness with numerous fossils indicating Cambrian and possibly lowest Silurian horizons (p. 920).
		Serpulite grit and "Fucoid beds," with *Salterella* and *Olenellus* Olenellus-zone.
		Quartzites with abundant worm-burrows.
		[Unconformability.]
Pre-Cambrian.	Torridonian.	Dull red sandstones, shales, and conglomerates attaining a thickness of at least 8000 or 10,000 feet, the upper limit being lost by denudation and unconformability.
		[Strong unconformability.]
	Lewisian.	Coarse gneisses and schists derived by mechanical deformation from a complex aggregate of eruptive rocks of different ages. In one area there appears to be a group of still more ancient sedimentary rocks through which the gneisses have been intruded.

LEWISIAN.—The oldest gneisses of Scotland form the Isle of Lewis with the rest of the Outer Hebrides, and extend in an interrupted band on the mainland from Cape Wrath at least as far as Loch Duich. For this important and well-defined group of rocks the name Lewisian, proposed by Murchison, seems most appropriate. As originally studied, it was thought to be a comparatively simple formation. Its foliation-planes, like those of other similar rocks, were supposed to mark layers of deposit, and to show that the rocks were metamorphosed sediments. It was believed to have been thrown into sharp anticlinal and synclinal folds, of which the axes ran in a general north-westerly direction. The detailed mapping of the region by the Geological Survey, however, has shown that the apparent bedding is wholly deceptive, and that the seeming simplicity gives place to an extraordinarily complex structure.[2] The rocks have been ascertained to consist of two great groups: (A) an intricate intermixture of various basic, intermediate, and acid materials, which constitute by far the largest proportion of the whole, and have been termed the "Fundamental complex," and (B) a succession of dykes, by which the complex has in pre-Cambrian time been traversed (Fig. 364).

(A) The fundamental and predominant part of the Lewisian series consists of various more or less banded, but sometimes amorphous and massive, rocks, which have all been

the Report by the Geological Survey, in *Q. J. G. S.* vol. xliv. (1888), p. 378. The more important announcements since that date will be referred to in the sequel.

[1] *Brit. Assoc.* 1891, Sect. p. 633. Peach and Horne, *Q. J. G. S.* xlviii. (1892), p. 227, and the Annual Reports and Summaries of Progress of the Geological Survey from 1893 onwards.

[2] On the gneiss of N.W. Scotland, see *Q. J. G. S.* xliv. (1888), p. 378, where the work of Messrs. Peach, Horne, Gunn, Clough, Hinxman, and Cadell is summarised. A detailed official memoir on the region is now in preparation. The pre-Cambrian deformation described in the text is much more ancient than the regional metamorphism discussed *ante*, p. 792.

included in the general appellation of gneiss. This oldest and main constituent, regarded simply from the petrographical point of view and without regard to theoretical questions as to origin, has been classified by Mr. Teall in the following five chief types.[1] I. Rocks composed of ferro-magnesian minerals, without felspar or quartz: (1) Pyroxenites; (2) Hornblendites. II. Rocks in which pyroxenes are the dominating ferro-magnesian constituents, felspar always present, and in some cases quartz: i. without quartz: (*a*) Hypersthene-augite-rocks, with garnet (pyroxene granulites); without garnet (rocks of the Baltimore-gabbro type); (*b*) Augite-rocks, gabbros in structure and composition, but forming part of the fundamental complex, and often associated with quartz-bearing rocks of a similar character: ii. with quartz; augite-gneiss. III. Rocks in which hornblende is the dominating ferro-magnesian constituent: i. without quartz or containing it only in small quantity; rocks basic in composition: (*a*) Massive or only slightly foliated; amphibolites with epidote, zoisite, or garnet; (*b*) Foliated; hornblende-schist (frequently foliated dykes): ii. with quartz; rocks intermediate or acid in composition; (*a*) Rocks with compact hornblende and a granular structure (hornblende-gneiss, proper); (*b*) Rocks with hornblende in fibrous or other aggregates; (*c*) Rocks with compact hornblende and a more or less granulitic structure (granulitic hornblende-gneiss). IV. Rocks in which biotite is the dominating ferro-magnesian constituent; felspar and quartz both present: (*a*) Biotite occurring as independent plates or in aggregates of two or three large individuals (biotite-gneiss, proper); (*b*) Biotite occurring in aggregates of numerous small individuals (a rare type); (*c*) Biotite occurring as independent plates, structure granulitic. V. Rocks in which muscovite and biotite are present, together with felspar and quartz—muscovite-biotite-gneiss.

Although the rocks of these five groups find on the whole their nearest analogies among deep-seated eruptive masses, they include in at least one district certain rocks, probably of sedimentary origin, consisting of mica-schists, graphitic-schists, quartzites, and siliceous granulites, limestones and dolomites, chlorite-schists, kyanite-gneiss, and sillimanite-garnet-schist, to which further reference is made on p. 890.

(B) The system of dykes by which the fundamental complex is traversed has been arranged by Mr. Teall in the following five petrographical types. I. Ultra-basic: (*a*) Massive, peridotites; (*b*) foliated, talcose schists containing carbonates and sometimes gedrite. II. Basic: (*a*) Massive,—dolerite, epidiorite; (*b*) Foliated, —hornblende-schist. III. Dykes of peculiar composition: (*a*) Microcline-mica-rocks; (*b*) Biotite-diorite, with macropoikilitic plagioclase. IV. Granites and Gneissose granites: Biotite-granite with microcline. V. Pegmatites: Microcline-quartz rocks with a variable amount of oligoclase or albite.[2]

In some parts of the region, where deformation has been least, the rocks have retained much of what was probably their original character, and can be recognised as syenite, diorite, gabbro, peridotite, picrite, pyroxene-granulite, or other massive amorphous member of the eruptive rocks. From these structureless areas, gradations can be traced into well foliated masses and into coarsely-banded gneisses, where the minerals have segregated into lenticular bands and elliptical or irregular concretions. Though it may often be difficult in practice to distinguish types of structure among these rocks, two such types may in many instances be recognised. In the first place, there is the banded or segregated structure, in which the predominant minerals have separated out from each other, and have crystallized more or less apart, often in coarse aggregations, forming in this way distinct bands or folia, which, since they are often crossed by the planes of foliation (Figs. 362, 368), are evidently older than the development of these planes. The bands consist sometimes of pyroxene or hornblende, with little or no plagioclase, or of plagioclase with small quantities of the ferro-magnesian minerals and quartz, or mainly of plagioclase and quartz, or largely of magnetite. This structure probably

[1] *Ann. Rep. Geol. Surv.* 1894, p. 280; 1895, p. 17 of Reprint.

[2] *Ann. Rep. Geol. Surv.* 1895, p. 18 of Reprint.

belongs to the time when the rock existed as an erupted material. It resembles in many respects the segregation layers in some sills or bosses of eruptive materials (gabbros, dolerites, &c.) which have cooled and crystallized slowly at some considerable depth from the surface. In the second place, there is abundant evidence of mechanical deformation of the gneiss, especially along planes in certain directions. The rock has been powerfully ruptured and crushed in these lines, and has thereby acquired a granulitized and distinctly foliated structure.

Both in the massive and in the coarsely-banded gneisses of the fundamental complex abundant pegmatite veins occur, which vary in width from a few inches to several yards, and consist mainly of felspar and quartz. These grey veins, sometimes so numerous as to constitute a large porportion of the whole rock, occasionally enclose patches of the dark more basic rock around them, but have no determinate grouping (Fig. 360). They

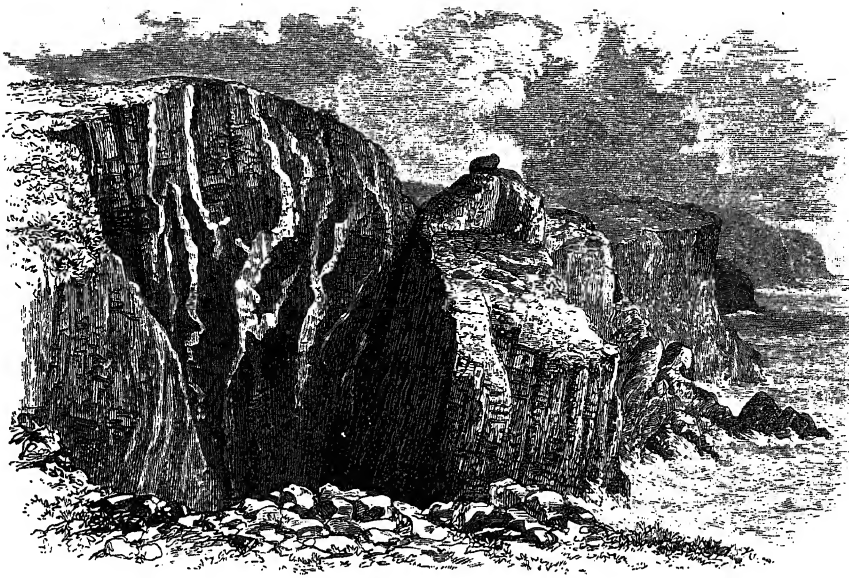

Fig. 360.—Veins of pegmatite in gneiss, south of Cape Wrath.

have played an important part in the ultimate constitution of the gneiss. Where still quite traceable, but where they have come within the influence of mechanical deformation, they appear as rudely parallel and puckered bands (Fig. 361). But as we pass into the more thoroughly foliated portions of the gneiss, the original character of the pegmatites is found to be more and more affected, until it becomes no longer recognisable in the acquired schistose structure. The dark basic portions of the original mass pass into rudely foliated basic gneisses, and the grey pegmatites shade into the more quartzose bands associated with them. Thus the derivation of the gneisses from amorphous igneous rocks may be regarded as established beyond dispute.

As illustrative of the conclusion that while there seems good reason to believe that the segregated or coarsely-banded structure indicates a separation and crystallization of materials out of a still unconsolidated igneous magma, the predominant foliation structures which traverse these bands were produced by powerful mechanical movements, such a section as that presented in Fig. 362 may be cited. The mineral bands have there been violently plicated, and have been cut through by a succession of thrust-

planes (t t), by which they have been pushed forward and piled over each other. The foliation (indicated by the fine parallel lines in the diagram) thus superinduced follows

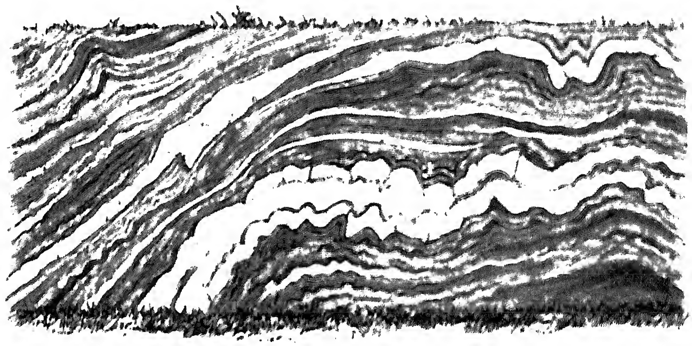

Fig. 361. Gneiss with deformed pegmatites. Cape Wrath.

the direction of movement, and crosses indiscriminately the boundaries of the different aggregates of original materials. Viewed from a little distance the darker and lighter crumpled layers form a striking feature on many coast cliffs, but they are seen to be abruptly truncated above and below by thrust planes parallel to which the gneiss has sometimes been crushed and rolled out into flaggy sheets (Fig. 363). These ancient structures are similar to those so abundantly developed in the younger or eastern gneisses already (p. 796) referred to. They seem to make it certain that after the consolidation of the complex assemblage of igneous rocks and the production of their pegmatites, a series of powerful mechanical movements crumpled, crushed, and sheared the whole mass, and produced in it a distinct foliation. Portions of one kind of material, such as dark hornblende, have been separated from the rest, and have been involved as distinct lumps in another variety, such as grey quartzose gneiss.

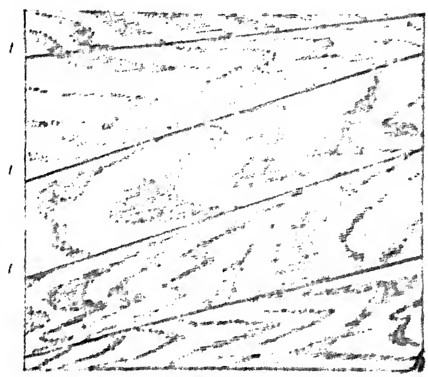

Fig. 362.[1] Section of Lewisian gneiss, embracing a vertical surface of several hundred square yards.

The detailed investigations of the Geological Survey have further shown that, after the first foliation had been superinduced in the fundamental complex, a new series of igneous protrusions invaded the gneisses, chiefly in the form of dykes. The petrographical characters of these later intrusions have been given above, and their general distribution is shown in Fig. 364, which represents an area of about twelve square miles in the west of Ross-shire. The earliest and most conspicuous of them consist of a remarkably abundant series of dolerite dykes running in long parallel bands in a general W.N.W. and E.S.E. direction (B in the Fig.). The latest are dykes of granite or syenite, while probably of intermediate date, are certain highly basic dykes, among which

[1] Figs. 362, 366-369, are taken by permission of the Council of the Geological Society from the Report of the Geological Survey published in the Quarterly Journal of the Society for August 1888.

peridotite and picrite are characteristic (P). The evidence as to the relative dates of these

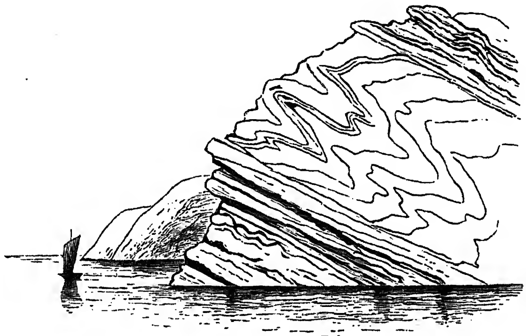

Fig. 363.—Plicated banded gneiss between masses that have been sheared parallel to the thrust-planes, north side of Loch Torridon.

igneous intrusions being tolerably clear, we have here proofs of a long interval of subterranean activity, during which the magma that was first injected into the gneiss

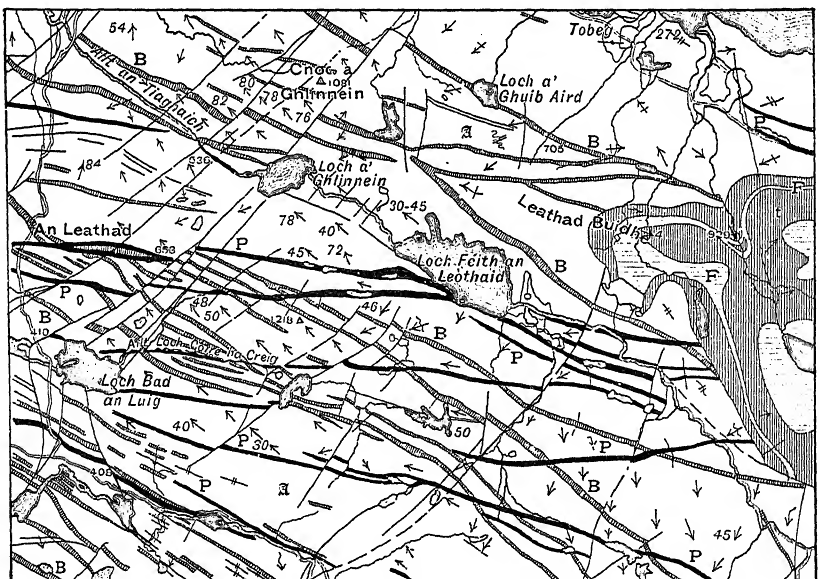

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Fig. 364.—Map of a portion of the Lewisian Gneiss of Ross-shire.

Taken from Sheet 107 of the Geological Survey of Scotland on the scale of one inch to a mile. The white ground (𝔄) marks the general body (fundamental complex) of the gneiss, traversed by dykes of dolerite (B), which are cut by later dykes of peridotite, picrite, &c. (P). All these rocks are shifted by faults or thrusts and overlain unconformably by the Torridon Sandstone (*t*) with its intrusive sheets of oligoclase-porphyry (F). Dip of foliation shown by arrows.

in such basic form as dolerite parted progressively with its more basic constituents until it became in the end quite acid. It is interesting to find, even among the most ancient

rocks of Britain, a sequence of eruptive materials, from basic to acid, like that which appears so markedly among the Palæozoic and Tertiary volcanic phenomena (p. 709).

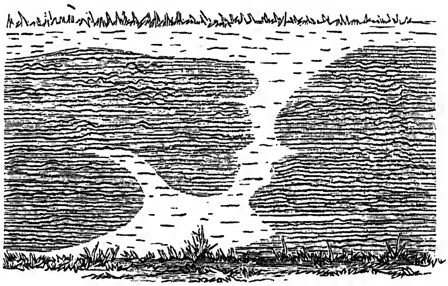

Fig. 365.—Foliation induced in a granite vein in gneiss, Loch Laxford.

After the injection of these various eruptive materials, the whole region of the north-west of Scotland was once more subjected to powerful dynamic movements, whereby all the rocks were profoundly affected. The results of these operations are found partly in vertical lines or bands of rupture or crushing (Figs. 364, 366), along which, sometimes for a breadth of 500 feet or more, the rocks have been crushed or sheared, partly in thrust-

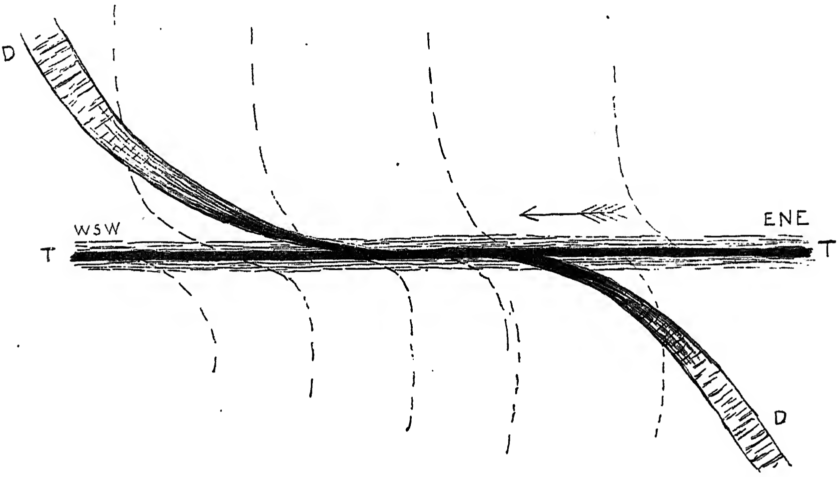

Fig. 366.—Ground-plan illustrating the deflection and disruption of the dykes in the Lewisian gneiss of N.W. Scotland.

TT, Crush-line or Thrust; DD, Dyke, deflected about ½ mile and much compressed. The dotted lines show the strike of the gneiss and its displacement by the thrust; the fine parallel lines in the dyke and in the gneiss mark the direction of the newer schistosity developed by the thrust-movement, which was in the direction of the arrow.

planes which are often nearly flat (Figs. 344, 369). In some instances the intrusive dykes remain quite distinct, but have acquired a more or less distinct foliated structure, the planes of foliation being parallel to those which traverse the surrounding gneiss (Fig. 365). But the alterations produced by these enormous terrestrial stresses are most strikingly displayed by some of the more basic dykes.

Along the central portions of one of the basalt or dolerite dykes, the massive rock

has been broken into oblong lenticles round which the more crushed material passes into hornblende-schist, while the outer portions of the dyke likewise become entirely schistose (Fig. 367; compare Fig. 266). So great has been the metamorphism even in the lenticles that the augite has been mostly changed into hornblende; the felspars have assumed an opaque granular condition, and the rock becomes a diorite. The peridotite and picrite dykes have been converted into soft talcose schists, the veins and belts of granite into granitoid gneiss. Such, too, has been the compression that in some cases dykes of 50 or 60 yards in breadth are reduced, where one of these thrusts or crush-lines crosses them obliquely, to a thickness of no more than four feet, while the horizontal displacement sometimes amounts to a quarter of a mile (Fig. 366). Besides foliation produced parallel to the vertical or highly inclined lines of movement, a similar structure has been superinduced in the gneiss parallel to the gently inclined thrust-planes.

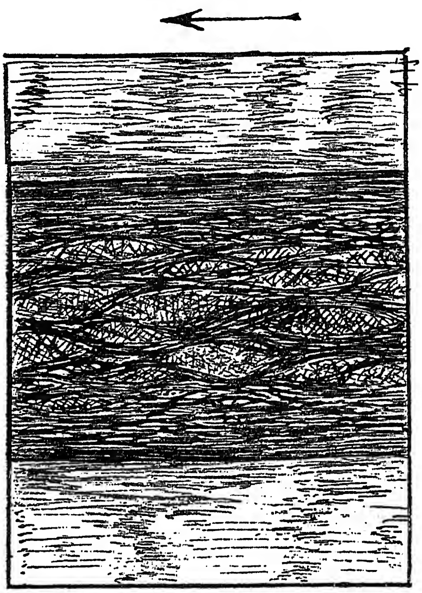

Fig. 367.—Diagram of dolerite dyke cutting Lewisian gneiss, representing an area of about 600 square yards. The dark portion represents the dyke with its "eyes" or lenticles surrounded by and passing marginally into hornblende-schist. The grey band on either side of the dyke is the surrounding gneiss which has been affected by a secondary foliation parallel to that of the dyke. The arrow shows the direction of movement.

The influence of these later movements, not only on the amorphous dykes and veins, but on the general body of the already foliated gneiss itself, has been profound. Where the change has been most complete, a new foliation has completely obliterated the original structure. From this extreme every gradation may be traced, back to the first schistose structure, and thence into the original amorphous condition. In many cases this new foliation has been produced nearly or quite along the planes of the old structure. But

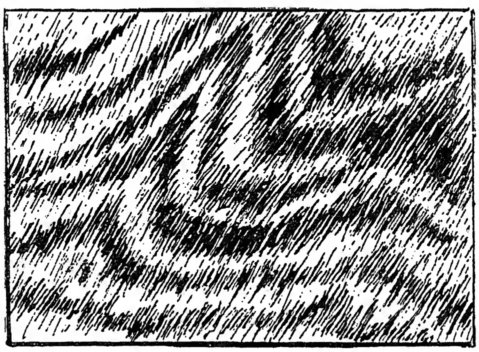

Fig. 368.—Diagram showing later oblique foliation crossing the original banding of the Lewisian gneiss (about nat. size).

everywhere examples may be observed where the alternate folia of lighter and darker material are traversed obliquely by the newer structure, which may be perfect in the dark more basic bands and hardly developed in the grey more quartzose parts.

The various terrestrial movements indicated by the complex composition and structure of the Lewisian gneiss must not be confounded with the post-Cambrian disturbances of the same region which produced the regional metamorphism already described (p. 792). The whole of them had been completed, and the rocks in which they took place at a great depth had been exposed at the surface by vast denudation before the next member of the pre-Cambrian series was formed. The Torridon sandstone lies unconformably on the old gneiss, covering alike its dykes, crush-lines, and thrust-planes, by not one of which is it in the least degree affected. It is of course impossible to form any adequate conception of the length of time denoted by this unconformability. But the more the geologist tries to realise what the denudation of the old gneiss involves, the more impressed will he be with the vastness of the period which it denotes.

Over nearly the whole of the Lewisian gneiss, so far as it has been studied on the mainland, no trace has been found of any rocks save what probably had an eruptive origin. In at least one district, however, which includes the picturesque valley of Loch Maree, a remarkable group of rocks occurs to which allusion has already been made (p. 883). Though their exact relations are not without some doubt, these rocks appear to indicate a sedimentary series through which the Lewisian gneiss has been erupted. They consist chiefly of fine mica-schist, quartz-schist, graphite-schist, and limestone. The graphitic material occurs in bands an inch or more thick in the mica-schist. The limestones are persistent beds, having generally a saccharoid texture, and sometimes full of the usual minerals found in marble in a zone of contact-metamorphism. The line of junction of this group of rocks with the gneiss is well defined, but does not distinctly show any intrusion of the latter, appearing rather to have resulted from movement with concomitant crushing. If these strata, so similar in many respects to rocks in the central Highlands, are eventually proved to be truly of sedimentary origin, they will possess a high interest as the oldest geological formation of which the stratigraphical position has been definitely fixed in Britain or in Europe.[1]

In some portions of the north-west of Scotland, especially in the north of Sutherland, the surface of the gneiss has been reduced, after prolonged denudation, to a kind of level platform on which the Torridon Sandstone has been deposited. But farther south that surface presents a singularly uneven character, rising into heights 3000 feet above the sea and sinking into hollows that descend below sea-level. In the rugged mountainous ground between Lochs Maree and Broom, this primeval land-surface is impressively displayed, for the thick mantle of red sandstone under which it was buried and preserved has been irregularly stripped off, and the details of the pre-Torridonian topography can easily be traced.

Torridonian.—From Cape Wrath, at the extreme north-west end of Scotland, southwards for more than 100 miles, there stretches a broken belt of singular conical or pyramidal hills, rising sometimes to more than 3000 feet above the sea, and presenting alike in their form and colouring a striking contrast to the rest of the scenery of that region. They are chiefly built up of nearly horizontal or gently inclined strata of reddish-brown or chocolate-coloured sandstones and conglomerates. As they are abundantly displayed among the mountains that surround Loch Torridon, one of the most picturesque inlets in the north-west of Scotland, they were called by Nicol the "Torridon Sandstone." They were originally supposed to be Old Red Sandstone, and to represent the lower sandstones and conglomerates of that system as developed in the east of Sutherland and Ross. After the discovery of what were believed to be Lower Silurian fossils in the Durness limestones, which overlie the Torridon sandstones,

[1] See *Brit. Assoc.* 1891, Sect. p. 634. Similar rocks have now been traced south-westwards into Glenelg. *Summary of Progress of Geol. Survey*, 1897, p. 37; 1899, p. 17; 1900, p. 8.

Murchison assigned these sandstones to the Cambrian system. But the recent detection of the Olenellus-zone among the strata which rest unconformably upon them proves that they must be of still older date. They are now classed as "Torridonian" in the pre-Cambrian formations or systems of Britain.

The strata now to be described repose with a violent unconformability on the Lewisian gneiss, and are in turn covered unconformably by certain quartzites to be afterwards more fully referred to as forming the base of the Cambrian system. Where most fully developed, in the south-west of Ross-shire and in Skye, they are between 10,000 and 14,000 feet thick. The following subdivisions have been recognised among them by the Geological Survey.[1]

4. Cailleach Head Group: sandstones, flags, dark and black shales and calcareous bands. 1000 to 1500 feet.
3. Aultbea Group: chocolate-coloured and red sandstones, and grey micaceous flags, with partings of grey, green, and dark shale. 2000 to 3000 feet.
2. Applecross Group: coarse arkose, with pebbles of vein-quartz, quartzite, quartz-schist, mica-schist, felsite, jasper, &c. 4000 to 5000 feet.
1. Diabeg Group: hard red sandstones and grits, grey greywackes, red mudstones, dark grey and black shales, limestone and calcareous bands; 500 feet and upwards, but increasing westwards in Skye to perhaps 5000 or 6000 feet, and consisting there chiefly of grits, which at the base are highly epidotic, and include on the mainland a conglomerate which rests on the upturned edges of the gneiss.

An examination of the pebbles in the conglomerates has shown that schistose or metamorphic rocks are rare among them except in the basal breccias and conglomerates. They include a number of rocks that have not been detected in any part of the Lewisian gneiss. The most interesting of these are pebbles of various felsites, in which spherulitic and perlitic structures can be recognised, and which present a striking resemblance to the Uriconian felsites of Shropshire (p. 896), fragments of which occur in the Longmyndian rocks.[2]

These pebbles in the Torridonian sediments indicate the existence of volcanic rocks at the surface during the time when the strata were being deposited, but no such rocks have yet been met with in place in the north-west of Scotland. The conglomerates at the base of the Torridonian series are occasionally so coarse as to deserve the name of boulder-beds. Sometimes, indeed, where the component blocks are large and angular, as at Gairloch, they remind the observer of the stones in a moraine or in boulder-clay.[3] The sandstones or arkoses of the thick and characteristic Applecross group are in large measure composed of pink felspar, derived from such rocks as the pegmatites of the surrounding gneiss. An occasional thin band may be found in the lowest group, consisting largely of grains of magnetite and zircon, whence we learn at what an ancient epoch in geological history heavy and durable grains were separated out from the more ordinary sediment (see p. 163). The highest visible or Cailleach Head group, and also the lowest (Diabeg), include shales, limestones, and calcareous bands, which have been carefully searched for fossils, but hitherto without success. Certain track-like and other markings are suggestive of organisms. Perhaps a surer indication is afforded by the occurrence of phosphatic nodules in the dark micaceous shales of Cailleach Head, which may be of organic origin, and in which Mr. Teall has detected under the microscope certain spherical cells with brown-coloured fibres in them, that appear to be debris of organisms.[4]

Thick as the Torridonian groups of strata are, they represent only a portion of the

[1] *Ann. Rep.* for 1893, p. 263.

[2] Mr. Teall, *Ann. Rep. Geol. Surv.* 1895, p. 20 of Reprint.

[3] A. G., *Nature*, xxii. (1880), p. 402.

[4] *Summary of Progress of Geol. Surv.* for 1899, p. 185.

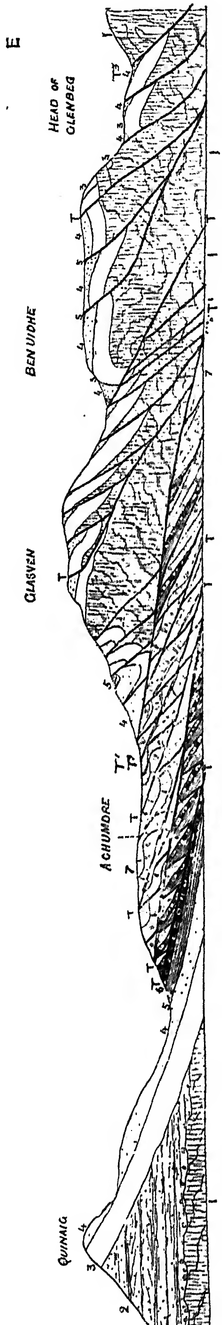

Fig. 369.—Section from Quinaig (2653 feet) eastwards through Glasven (2541 feet), Sutherland (*Quart. Journ. Geol. Soc.* 1888, p. 418). Cambrian.—7, Limestone; 6, Serpulite grit; 5, Fucoid beds with *Olenellus*-zone; 4, 3, Upper and lower Quartzite. Pre-Cambrian.—2, Torridon Sandstones; 1, Lewisian gneiss. T, Minor Thrust-planes; T', Maximum Th[rust-plane].

geological period which they record, for their base rests unconformably and at different horizons on the Lewisian gneiss, while their upward prolongation above the highest remaining group has been removed by denudation. There can be no doubt that the interval between the deposition of the highest visible portion of the Torridonian series and the base of the Cambrian formations must have been of prolonged duration. For not only had the red sandstones been upraised, but they had been profoundly trenched by denudation. So vast and unequal was the erosion that while at one place the lower quartzites are seen reposing on 3000 to 4000 feet of Torridon sandstone, at another only a few miles distant they rest directly on the Lewisian gneiss, the intervening massive group of strata having been entirely bared away.[1]

As already described (p. 792), there are extensive tracts where the pre-Cambrian rocks do not remain in their original positions, but have been pushed into their present places by great subterranean disturbances, and have actually been shoved over strata of recognisably Cambrian age. In the detailed account above given of the structure of north-west Scotland it was shown that by these earth-movements slice after slice, sometimes gigantic in dimensions, of the Lewisian gneiss and of the Torridonian sandstone have been shorn from the mass of these formations below ground, have been piled one on the other, and have been driven for miles westward over the Cambrian strata which originally lay above them; that the rocks subjected to such enormous pressure, dislocation, and deformation have undergone serious metamorphism; and that finally by a gigantic rupture and thrust a thick series of gneissose flagstones ("Moine schists") has been brought forward. By way of further elucidation of this extraordinary structure the annexed section is given (Fig. 369). It will be seen what an enormous body of gneiss has here been displaced and pushed over the Cambrian strata, which in turn have been cut into slices and piled up above and against each other. Among the alterations of the Torridon sandstones one of the most interesting is the production of pegmatitic veins in them, like those which traverse eruptive rocks. These strata have been crushed and stretched in such a manner that ruptures, often lenticular in form, have been produced in them. In the cavities thus caused there has been a deposition of quartz and of quartz and pink felspar (Figs. 268 and 345).

Of many of the rocks which have been thus displaced and metamorphosed, it is extremely difficult to form a satisfactory opinion regarding the

[1] This structure is shown both in Figs. 344 and 369.

probable source and original condition. The larger displaced slices have preserved their original structure best, and there is thus little difficulty in generally recognising those of Lewisian gneiss. We have seen that in the west of Inverness-shire some of these slices are much more than 50 square miles in area. Hence in that region this gneiss probably constitutes a large proportion of the reconstructed schistose series which has been thrust westward over the Torridonian and Cambrian formations. The Torridon sandstones likewise can be occasionally identified, and may constitute a not inconsiderable proportion of the "Upper gneiss" of Western Ross-shire. Possibly other sedimentary material, such for instance as the Durness quartzites, dolomites, and limestones, together with any strata which were deposited above them, may have been involved in the gigantic crushing movements that produced the younger or eastern schists. As the detailed work of the Geological Survey advances the sources from which these schists have been derived may be more fully known. But the great fact has been abundantly established that the movements which pushed the rocks into their present positions and imparted to them their existing foliation took place after Cambrian time, and before the period of the Old Red Sandstone. We have thus a notable example of extensive regional metamorphism during the Palæozoic ages.

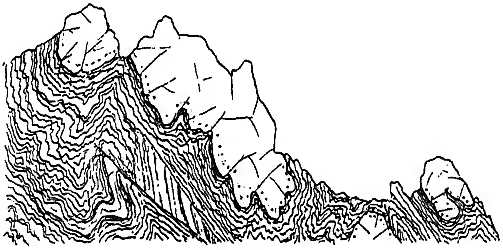

Fig. 370.—Amphibolite sill in gneiss, Ardachy, Isle of Mull.

Dalradian.—In the central, southern, and eastern Highlands of Scotland, that is, throughout the hilly ground east and south of the line of the Great Glen, an important series of metamorphic rocks is largely developed, the true stratigraphical position of which is not yet certainly known. For these, as a convenient provisional designation until their relations are determined, I proposed in 1891 the term Dalradian.[1] They consist in large proportion of altered sedimentary strata, now found in the form of mica-schist, graphite-schist, andalusite-schist, phyllite, schistose-grit, greywacke, and conglomerate, quartzite, limestone, and other rocks, together with epidiorites, chloritic schists, hornblende-schists, and other allied varieties which probably mark sills (Fig. 370), lava-sheets, or beds of tuff, intercalated among the sediments. The total thickness of this assemblage of rocks must amount to many thousand feet. Some of its members are so persistent as to form recognisable horizons, and to afford a basis for some approximation to a stratigraphical arrangement of the whole. In Perthshire, for example, the following groups in descending order have been mapped by the Geological Survey :—

Dark schist and limestone (Blair Athol).
Quartzite (Ben-y-Gloe).

[1] *Q. J. G. S.* xlvii. p. 75. "Dalradian" is taken from the old Celtic region of Dalriada, where the rocks are well developed. The term is not meant to describe an independent geological system, but as a short epithet to denote a group of rocks, of which the precise stratigraphical relations are not yet determined. The fullest published accounts of these rocks will be found in the *Annual Reports and Summaries of Progress of the Geological Survey* from 1893 onwards.

Graphite-schist.
Calcareous sericite-schist, and sericite-schist with bands of quartzite. On this horizon occurs a great mass of epidiorite and hornblende-schist.
Garnetiferous mica-schist and schistose pebbly grits.
Limestone (Loch Tay). Hornblende-schists occur above and below this horizon (Fig. 371).
Garnetiferous mica-schists, schistose grits, with pebbly bands and thick bands of "green schists." Hornblendic sills begin to appear in this group.
Massive grits with schists and conglomerate containing pebbles sometimes as large as a pigeon's egg. (Ben Ledi, Loch Achray, &c.).
Zone of slates (Aberfoyle).
Pebbly greywacke and grit with black shales and limestone below (Pass of Leny).

The Loch Tay Limestone has now been traced completely across the country from the Moray Firth through the Grampian Mountains to the west of Argyllshire, and some of the other zones have been followed for many miles. As we have seen, the metamorphism of the rocks varies considerably, not only according to their composition, but even along the line of strike of the same group. On the whole, the plication, corrugation, and alteration appear to be most intense in the Central Highlands, as indicated in Fig. 371, and to become less as the rocks recede from that area towards the north-east and south-west. One of the most singular and instructive instances of this variation is that which has already (p. 796) been cited as having been mapped by Mr. J. B. Hill, of the Geological

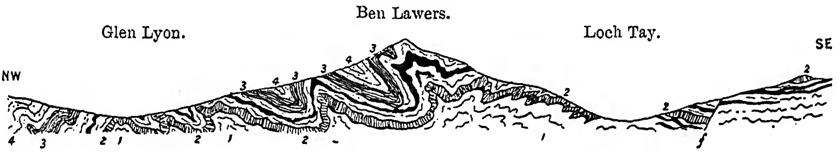

Fig. 371.—Showing the corrugation of the Dalradian series in Central Perthshire. 1, Mica-schist; 2, Loch Tay Limestone; 3, Graphitic schist; 4, Quartz-schists. The black bands are sills of epidiorite.

Survey, in the district of Loch Awe, where a series of grits, phyllites, and limestones, resembling ordinary Palæozoic sediments, has been found to pass along the strike into the thoroughly crystalline schists of the Central Highlands.

Although it is still impossible to express a definite opinion as to the stratigraphical position of the Dalradian rocks, there is reason to believe that, like the series which lies on the west side of the Great Glen, they may include representatives of the Lewisian, Torridonian, and Cambrian groups of the north-west Highlands, and not improbably also of a considerable mass of later, even of Lower Silurian strata. Some of the gneisses and gneissose flagstones are strongly suggestive of parts of the series of Western Sutherland and Ross. The quartzites of Perthshire, Islay, and Jura, so similar lithologically to those of the Cambrian series of the north-west, have yielded annelide burrows like those of Sutherland and Ross. Still more significant is the occurrence of what are probably Arenig strata wedged in along the southern borders of the Highlands. The latest orogenic and metamorphic stresses that have affected that region certainly took place after these strata had been deposited (p. 797). This subject will be further referred to in connection with the distribution of the Silurian formations in Scotland (p. 951).

In the north and west of Ireland, crystalline schists and eruptive rocks cover a large area; but as the rocks which unconformably overlie them are not of higher antiquity than the Carboniferous and Old Red Sandstone, there is no absolute proof in that country of their pre-Cambrian age. There cannot, however, be any doubt that it is the Dalradian series of limestones, quartzites, phyllites, mica-schists, epidiorites, granites, and other crystalline rocks, which crosses from Scotland and spreads across the northern and western counties of Ireland. The Irish development of these rocks is similar to their grouping in Scotland, some of the bands of quartzite, conglomerate, limestone, phyllite,

and mica-schist being probably continuations of similar bands on the Scottish mainland and in the islands of Argyllshire.[1] But there are also scattered areas of coarsely-banded gneisses which present the closest resemblance to parts of the Lewisian gneiss of Scotland. The best areas for the study of these rocks lie near Pettigoe and Ballyshannon (Donegal), from Erris Head to Blacksod Point (Mayo), in the Slieve Gamph or Ox Mountains stretching from Castlebar beyond Sligo to Manor Hamilton, and in the western part of the county of Galway. The relations of the Dalradian series to the gneisses and granitoid rocks have not been accurately determined. But there is reason to believe that the former rests with a violent unconformability upon the latter. Near Castlebar, Mr. A. M'Henry, of the Geological Survey, has found at the base of the Dalradian schists a coarse conglomerate made up largely of fragments of the gneisses and granites on which it rests.

In England and Wales, a number of detached areas of rocks have been claimed as pre-Cambrian, though the stratigraphical evidence for their age is not generally very clear. The tract where such rocks are most extensively exposed and where their stratigraphical position is best seen is to be found in Anglesey. Although the *Olenellus*-zone has not been discovered, the fossils found in the lowest strata indicate Tremadoc and possibly even Menevian horizons in the Lower Cambrian series.[2] At the base some conglomerates evidently lie with a marked unconformability on certain crystalline schistose rocks. It was the belief of Sir A. C. Ramsay that the latter were metamorphosed portions of the Cambrian system, and they were so represented on the Geological Survey maps. But a re-examination of the ground leads to the conclusion that they had acquired their present crystalline characters before the Cambrian strata were laid down upon them; and as these strata belong to a low part, if not the base, of the Cambrian system, it becomes manifest that the schists must be of pre-Cambrian age.[3]

Three groups of schistose rocks, which differ considerably in petrographical characters, have been detected in Anglesey. One of these, consisting mainly of coarse gneisses, abounding in hornblende, garnets, and brown mica, and with coarse pegmatite veins, presents a close resemblance to portions of the Lewisian series of N.W. Scotland. The second group occupies a much larger area, and is composed of flaggy chloritic schists, green and purple phyllites or slates, quartzite, grit, and other more or less recognisably clastic rocks. The resemblance of these masses to the Dalradian series of Scotland and Ireland is striking. The quartzites of Holyhead contain annelide burrows. The third group consists of chloritic schists, grits, phyllites, and shales, the stratigraphical relations of which have been much obscured by extreme disturbance.[4] The exact stratigraphical relations of these crystalline groups to each other have not yet been satisfactorily determined. It may, however, be regarded as a well-established fact in British Geology that

[1] The fullest account of these Irish metamorphic rocks will be found in the Memoirs of the Geological Survey of Ireland; see especially those on Sheets 1, 2, 5, 6, and 11 (Inishowen, Co. Donegal); 3, 4, 5, 9, 10, 11, 15, and 16 (N.W. and Central Donegal); 22, 23, 30, and 31 (S.W. Donegal); 31 and 32 (S.E. Donegal). See also Harkness, *Q. J. G. S.* xvii. (1861), p. 256; Callaway, *op. cit.* xli. (1885), p. 221.

[2] Professor Hughes, *Q. J. G. S.* xxxvi. (1880), p. 237; xxxviii. (1882), p. 16.

[3] Professor Hughes, *op. cit.* xxxiv. (1878), p. 137; xxxv. (1879), p. 682; *Brit. Assoc.* 1881, Sects. p. 643; *Proc. Camb. Phil. Soc.* iii. pp. 67, 69, 341. Professor Bonney, *Q. J. G. S.* xxxv. (1879), pp. 300, 321; *Geol. Mag.* 1880, p. 125. Dr. Hicks, *Q. J. G. S.* xxxiv. (1878), p. 147; xxxv. (1879), p. 295; *Geol. Mag.* 1879, pp. 433, 528. Dr. Callaway, *Q. J. G. S.* xxxvii. (1881), p. 210, xl. (1884), p. 567. Professor J. F. Blake, *op. cit.* xliv. (1888), p. 463; *Brit. Assoc.* 1888 (Report on Microscopic Structure of Anglesey Rocks). Address, *Q. J. G. S.* xlvii. (1891), p. 82. C. A. Matley, *op. cit.* lv. (1899), p. 635; lvi. (1900), p. 233; lvii. (1901), p. 20.

[4] I was disposed to regard this group as in part at least of Lower Silurian age, but the more recent and detailed surveys of Mr. Matley show that it is probably older.

early in the Cambrian period there existed at least one tract of old crystalline rocks above water in the north-west of Wales.

On the borders of Shropshire and Wales a ridge of ancient rocks rises up from under Silurian strata which lie upon it unconformably. Part of this ridge consists of eruptive material which was formerly believed to be of later date than the sedimentary rocks immediately around. But the main portion of the high ground is formed of a thick series of evidently very old grits, slates, and other clastic deposits, which, though hardly any trace of organic remains had been found in them, were assigned to the Cambrian system. More recent researches, however, have shown the presence of the *Olenellus*-zone in this district at the base of a group of strata, which are thus definitely proved to be lower Cambrian.[1] From this important horizon it is possible to work backward and to show that underlying these basement parts of the Cambrian system a remarkable group of igneous rocks comes to the surface. The investigations of Mr. Allport and Dr. Callaway have shown that these rocks include both lavas and fragmental ejections, varying from coarse breccias to fine tuffs. The lavas are generally felsitic in character, showing true rhyolitic structures, but there occur also bands of diabase which may possibly be sills. There is thus clear evidence of a copious ejection of volcanic materials in this part of England before the oldest Cambrian formations were laid down.[2]

Though the evidence is not perhaps conclusive, it seems to point to an unconformability between the base of the Cambrian system and this volcanic group, which would thus probably be of pre-Cambrian date. The relation of the volcanic masses to the great thickness of ancient sedimentary strata constituting the Longmynd ridge has not yet been satisfactorily determined, though there are indications that the volcanic group lies at the bottom. Dr. Callaway has proposed the name *Uriconian* for that group, and *Longmyndian* for the thick series of sedimentary strata lying to the westward. Those names may be provisionally accepted. The Longmyndian rocks have generally been assigned to the Cambrian system, and they may possibly still be shown to belong to that part of the geological record. The Uriconian volcanic group, however, is probably pre-Cambrian.

In other parts of England and Wales, isolated areas have been described as containing pre-Cambrian rocks. Of these the district of St. David's in Pembrokeshire has attracted the largest share of attention, chiefly through the prolonged and enthusiastic labours of the late Dr. Henry Hicks, who in that small area endeavoured to establish the existence of three distinct pre-Cambrian formations. At the base, under the name of 'Dimetian," he placed what he considered to be granitoid and gneissic rocks with bands of impure limestone or dolomite, schists and dolerite. Above these he distinguished as "Arvonian" a group composed essentially of rhyolitic felstones, breccias, and tuffs, marking volcanic eruptions of an acid type, while at the top he described by the designation "Pebidian," a series of tuffs and slates.[3] After a careful study of the ground I came to the conclusion that there is no trace of pre-Cambrian rocks at St. David's. I regard the so-called "Dimetian" as a granite which has invaded the Cambrian rocks; the "Arvonian" includes the quartz-porphyries, which appear as apophyses of the granite; while the "Pebidian" is an interesting group of basic lavas and tuffs which form here the lowest visible part of the Cambrian system (referred to at p. 919). A similar

[1] Lapworth, *Geol. Mag.* 1888, p. 484.

[2] S. Allport, *Q. J. G. S.* xxxiii. (1877), p. 449. C. Callaway, *op. cit.* xxxiii. p. 652; xxxiv. (1878), p. 754; xxxv. (1879), p. 643; xxxviii. (1882), p. 119; xlii. (1886), p. 481; xlvii. (1891), p. 109. *Geol. Mag.* 1881, p. 348; 1884, p. 362; 1885, p. 260; 1900, p. 511. J. F. Blake, *Q. J. G. S.* xlvi. (1890), p. 386.

[3] *Q. J. G. S.* xxxi. (1875), p. 167; xxxiii. (1877), p. 229; xxxiv. (1878), p. 153; xxxv. (1879), p. 285; xl. (1884), p. 507. My account of the so-called pre-Cambrian rocks of St. David's will be found in *Q. J. G. S.* xxxix. (1883), p. 261. Professor Lloyd Morgan has since confirmed my main conclusions, *op. cit.* xlvi. (1890), p. 241. Compare also J. F. Blake, *op. cit.* xl. (1884), p. 294.

group of breccias and tuffs underlies the Cambrian slates of Llanberis, and has likewise been claimed as pre-Cambrian, but it can be shown to pass up continuously into the Cambrian strata. In the Malvern Hills a core of gneissose and schistose rocks is doubtless of pre-Cambrian age, fragments derived from it being found at the base of the overlying unconformable Cambrian strata.[1] From the plains of Leicestershire rises an insular area of rocky hills (Charnwood Forest) composed of slates, tuffs, and various crystalline rocks, which by the Geological Survey have been coloured as altered Cambrian. Messrs. Bonney and Hill, who fully described these rocks, regarded them as of pre-Cambrian date, and showed to what a large extent they are composed of volcanic agglomerates and tuffs.[2] The rocks are immediately surrounded and overlain by Triassic sandstones, so that their relations to older rocks are concealed. Although there is thus no stratigraphical evidence to fix their age, they must be admitted to be lithologically different from any known Palæozoic series in the country. They may thus with some probability be regarded as pre-Cambrian. They have been recently mapped in detail by Messrs. Fox Strangways and W. W. Watts, of the Geological Survey, and present the following succession in descending order:—

Brand series, consisting of slates at the top, underlain by conglomerate and quartzite (containing worm-tracks), lying upon purple and green beds.
Maplewell series, composed of olive hornstones; Woodhouse beds, slate-agglomerate, hornstone of Beacon Hill, and felsitic agglomerate.
Blackwood series.[3]

Another protuberance of ancient rocks rises in Central England from beneath the coal-field of Eastern Warwickshire. In this instance a definite age can be assigned to one portion of the rocks, for they contain Upper Cambrian fossils.[4] Beneath these strata, and apparently in conformable sequence with them, lies a well-marked volcanic group which has been claimed as pre-Cambrian, but which may be the equivalent of the volcanic series ("Pebidian," p. 896) found elsewhere at the base of the Cambrian system (p. 919). At the Lizard Point in Cornwall a series of eruptive and schistose rocks occurs, the true relations of which have not yet been fixed, but which are probably pre-Cambrian. They include coarse gneisses which rise as islets near the coast.[5]

On the Continent of Europe numerous isolated areas of schists and other ancient rocks have been assigned to a pre-Cambrian or Archæan series. In the older descriptions of these tracts an order of succession and measurements of thickness were often given, the foliation being assumed to represent consecutive layers of deposition. But we now know that, in the great majority of cases, the foliation is entirely independent of original structure, so that the former attempts to establish a stratigraphical order among the gneisses and schists, and to compare that order in different countries, cannot be accepted. All that can be essayed here is to give a summary of the general characters of the most ancient rocks of each region referred to.

[1] J. Phillips, "Geology of the Malvern Hills," *Mem. Geol. Surv.* ii. Part 1. Holl, *Q. J. G. S.* xxi. p. 72. Rutley, *op. cit.* xliii. (1887), p. 481. Callaway, p. 525; *op. cit.* xlv. (1889), p. 475; xlix. (1893), p. 398; *Geol. Mag.* 1892, p. 545. T. Groom, *op. cit.* lv. (1899), p. 129; lviii. (1902), p. 89.

[2] *Q. J. G. S.* xxxiii. (1877), p. 754; xxxiv. (1878), p. 199; xxxvi. (1880), p. 337; xlvii. (1891), p. 78; li. (1895), p. 24.

[3] *Ann. Rep. Geol. Surv.* for 1895, p. 5; for 1896, p. 10. The middle subdivision includes some striking volcanic breccias and agglomerates.

[4] Lapworth, *Geol. Mag.* (1886), p. 321. T. H. Waller, *op. cit.* p. 323. Rutley, p. 557. A. Strahan, *Geol. Surv. Map*, Sheet 63.

[5] Bonney and Hudleston, *Q. J. G. S.* xxxiii. (1877), p. 884; xxxvii. (1883), p. 1; xlvii. (1891), p. 464. C. A. M'Mahon, *op. cit.* xlv. (1889), p. 519. H. Fox and J. J. H. Teall, *op. cit.* xlix. (1893), p. 199.

Scandinavia exhibits the largest continuous tract of pre-Cambrian rocks in Europe.[1] Although these rocks have been more or less minutely examined throughout the whole extent of the peninsula, and have been described in many papers and memoirs, the earlier published descriptions of them, though often excellent from the lithological point of view, were written before the revolution in the views of geologists regarding the complicated tectonics of regional metamorphism, while these views since their promulgation have been only but partially applied to the elucidation of the true relations and structure of the older rocks of the peninsula. There can be no doubt that these rocks are a prolongation of those which farther to the south-west rise out of the Atlantic in the Highlands of Scotland and the hills of the north and west of Ireland. And there seems every probability that the broad features of geological structure which have been ascertained to prevail in the British area will be found to extend also into Norway and Sweden.[2]

Wide tracts of western Norway consist of coarse-banded gneisses (Grundfjeldet, Urberget), which present the closest resemblance to the Lewisian series of Sutherland and Ross, but with a wider range of petrographical diversity. They include red and grey gneisses, banded and streaked granulites, epidote-gneiss, cordierite-gneiss, granites, syenites, gabbros, diorites, labradorite-rocks, garnet-rocks, amphibolites, peridotites, serpentines, &c. The general assemblage of these rocks suggests that they represent a complex series of acid and basic eruptive masses. With them is intimately associated another group of rocks, of which conspicuous members are quartzite, limestone, mica-schist, quartz-schist, and others which, like those of Loch Maree (p. 890), point with more or less clearness to a sedimentary origin. This group is usually quite crystalline, and is certainly older than some portions of the gneisses which can be seen to pierce it. It contains, however, bands of amphibolite, which may represent sills intruded between its component layers. Thus at Rukedal (Southern Norway) a mass, 3000 feet thick, of quartzite, quartz-schist, and interbedded seams of hornblende-schist, lies upon a group of hornblende-schists and grey gneiss traversed by abundant granite veins. Thin bands of limestone occasionally occur in the gneiss, as near Christiansand, where they have yielded many minerals, especially vesuvianite, coccolite, scapolite, phlogopite, chondrodite, and black spinel. Apatite with magnetite, titaniferous iron, hæmatite, and other ores forms a marked feature of the Norwegian pre-Cambrian series. The most important

[1] In the older literature consult Keilhau, 'Gaea Norvegica,' iii. (1850). Kjerulf, 'Udsigt over det Sydlige Norges Geologi,' Christiania, 1879 (translated into German by Gurlt, and published by Cohen, Bonn, 1880). A. E. Törnebohm, "Die Schwedischen Hochgebirge," *Schwed. Akad.*, Stockholm, 1873. "Das Urterritorium Schwedens," *Neues Jahrb.* 1874, p. 131. Karl Pettersen, "Geologiske Undersøgelser inden Tromsø Amt," *Arch. Norske Videnskab. Skrift.* vi. 44; vii. 261. For more recent work see Reusch's important monograph on the fossiliferous crystalline schists of Bergen, quoted on p. 785, also his instructive essay 'Bömmeloen og Karmoen,' 1888; his papers in the 'Aarbog for 1891' of the Geological Survey of Norway (*Norges Geologiske Undersøgelse*); his "Geologiske Iagttagelser fra Trondhjems Stift," *Christiania Vidensk. Selsk. Forhandl.* 1891; and his paper on "Crystalline Schists of Western Norway," *Compt. rend. Congrès. Geol. Internat.* 1888 (1891), p. 192. T. Dahll, O. A. Corneliussen, and H. Reusch, "Det nordlige Norges geologi," *Norges Geolog. Undersög.* 1892. C. H. Homan, "Sellu," *Norges Geolog. Undersøg.* 1890. Brøgger, *op. cit.* No. 11, 1893. Törnebohm, *Nature*, 1888, p. 127, and various papers during recent years in the *Geol. Fören. Forhandl. Stockholm*, especially vol. xiii. (1891), p. 37; xiv. (1892), p. 27; xv. (1893), p. 81; xvi. (1894), p. 661; xxiii. (1901), p. 206. P. J. Holmquist, *op. cit.* xxii. pp. 72, 105, 151, 233; xxiii. p. 55; and *Sverig. Geol. Undersökn.* No. 185 (1900).

[2] As the result of two journeys in Norway between Bergen and Hammerfest I was convinced of this general parallelism, but the determination of the detailed stratigraphy of the country will be a task of incredible labour, demanding from the Scandinavian geologists many years of patient application.

mineral masses in an industrial sense are thick beds and lenticular masses of iron-ore (Dannemora, Filipstad, &c.).

Of obviously later date than the coarse gneisses with their accompaniments is another series of crystalline schists which spreads over vast tracts of country in Scandinavia. Among these rocks mica-schists, phyllites, quartz-schists, clay-slates, quartzites, and schistose conglomerates are conspicuous, and indicate that a large proportion of the whole mass is probably of clastic origin. But there are also included chloritic and hornblende schists, amphibolites, gneisses, and many other rocks which were probably of eruptive origin, whether injected as sills or thrown out contemporaneously with the sedimentation of the schists as tuffs and lavas. In many respects this important series of schists bears a close resemblance to the "younger gneiss" or Dalradian series of Scotland. But its actual stratigraphy has not yet been accurately elucidated. That some part of it may be pre-Cambrian seems sufficiently probable. But its true relations are complicated by the discovery of Silurian fossils in some portions of the series, and by the apparent gradation of comparatively unaltered fossiliferous Silurian strata into the schistose condition. Dr. Hans Reusch, as already pointed out (p. 798), has shown that among the crystalline schists to the south of Bergen bands of fine mica-schist or phyllite with layers and nodules of limestone contain fossils probably of Upper Silurian age.[1] Having had an opportunity in 1889 of visiting the district, I have collected fossils from all the localities which he enumerates, and can entirely confirm the account which he gives of the thoroughly metamorphic character of the rocks among which the fossiliferous bands occur. The phyllites are intercalated among white quartzites, quartzite-conglomerates, green schists, hornblendic and actinolitic schists and gneisses. But for the occurrence of the fossils, a geologist would naturally class the rocks as probably of pre-Cambrian age. But the corals, graptolites, and other organic remains make it quite certain that the crystalline schists in which they occur underwent their great metamorphism not earlier than some part of the Silurian period. It will be an extremely difficult and laborious task to disentangle the complications of these Norwegian rocks, and to determine which are of pre-Cambrian and which of Palæozoic age. Dr. Reusch, summing up what is known regarding the distribution of fossils among these strata, believes that a more or less continuous belt of Cambrian and Silurian rocks, usually in an extremely metamorphosed condition, can be traced along the axis of the Scandinavian peninsula from near Stavanger to the North Cape.[2] A group of red arkoses and sandstones, thousands of feet in thickness, known as Sparagmite, covers a wide extent of the hilly country in the heart of Norway to the north of Christiania. The resemblance of these rocks to the Torridonian series of Scotland is remarkably close.

In Sweden a similar development of pre-Cambrian rocks may be traced. Two broad subdivisions among them have been recognised. The lower of these (Urberg) is grouped into an older series of grey and iron gneiss, banded gneiss, limestone, granite, &c., and a younger series of porphyries and hälleflinta gneisses and granites. The upper section consists of more or less obviously sedimentary formations, divisible into two series: the Dalarnian, composed more especially of reddish sandstones, shales, and conglomerates (3000 feet), and the Sevé, made up partly of arkose and sandstone,

[1] See the volume cited *ante*, p. 785. The younger Scandinavian gneisses and schists which overlie Cambrian and Silurian fossiliferous strata are referred to on pp. 922, 970. De Geer has recorded the occurrence of conglomerate among the "Archæan" gneisses, quartzites, and schists of Scania in the south of Sweden, *Geol. Fören. Stockholm.* viii. 1886, p. 30 (trans. by F. Wahnschaffe, *Z. D. G. G.* 1886, p. 271). Ninety-five per cent of its pebbles consist of grey quartzite, like the quartzite below (H. Backström, *Svensk. Akad. Handl.* xxix. No. 4 (1897), p. 23). Its composition rather suggests a brecciation of the quartzite *in situ* than a true conglomerate.

[2] See his sketch-map of Scandinavia and Finland (*Geologisk Kart over de Skandinaviske Lande og Finland*), Christiania, 1890.

and partly of various crystalline schists and limestone (Hedekalk of Sweden, Birikalk of Norway). The character of the sedimentary pre-Cambrian and Palaeozoic formations of Scandinavia is strikingly different on the eastern and western sides of the peninsula. Possibly a land-barrier may from the beginning have separated the areas of deposit, thus giving rise to an original difference in the nature of the sediments. But, as already pointed out (p. 798), the western side of the region has been subjected to gigantic disturbance, displacement and regional metamorphism. The original clastic deposits of the Seve group have thus been converted into mica-schists, with some hornblende-schists and garnetiferous gneisses. This altered form of the group covers a vast extent of the central fjelds, stretching as a broad band from Dalarne up to the northern parts of Sweden.[1]

Pre-Cambrian rocks cover most of **Finland**, where they present characters similar to those observed in Sweden. They have been well described by Sederholm, who has given a stratigraphical classification of them, and has especially called attention to some remarkable evidence of a sedimentary intercalation among them at Tammerfors. A conglomerate is there found to contain rounded and partially deformed pebbles of diorite, granite, syenite, porphyrite, phyllite, and quartzite. The variety of material of these stones and their obviously rounded and water-worn forms distinguish them from those of a friction-breccia or crush-conglomerate. The matrix is schistose, and can sometimes hardly be distinguished from the pebbles enclosed in it.[2]

Central Europe.—From Scandinavia and Finland a great series of pre-Cambrian crystalline schists stretches into the north-west of Russia, reappearing in the north-east of that vast empire in Petchora Land down to the White Sea, and rising in the nucleus of the chain of the Ural Mountains, and still farther south in Podolia. In Central Europe, similar rocks appear as islands in the midst of more recent formations. Among the Carpathian Mountains, they protrude at a number of points. Westwards of the central portion of the Alpine chain they rise in a more continuous belt, and show numerous mineralogical varieties, including gneiss, mica-schist, and many other schists, as well as limestone and serpentine.[3] Some of these rocks are certainly altered sedimentary deposits, others are probably crushed igneous rocks. The protogine of the Alps has been shown by Michel Lévy to be intrusive. It behaves to the surrounding schists as some parts of the Laurentian gneiss of Canada do to the schists next to that rock.

[1] See A. E. Törnebohm's papers in *Geol. Fören. Stockholm*, and in *Handl. Akad. Stockholm*, xxviii. No. 5, 1896; the Reports of the *Sverig. Geol. Undersökn*; also Nathorst's 'Sveriges Geologi,' 1894, and *postea*, pp. 925, 970.

[2] J. J. Sederholm, "Über eine Archaeische Sedimentformation im westlichen Finland," *Bull. Com. Géol. Finlande*, No. 6, 1899. His classification of the Finland pre-Cambrian formations will be found at p. 233 of this Memoir. Much information regarding these rocks is given in the maps and accompanying explanatory memoirs of the Geological Commission under Mr. Sederholm's direction, also in his papers in *Tschermak's Mittheil.* xii. (1891), pp. 1, 97; *Fennia*, viii. No. 3 (1893); *Geol. Fören. Stockholm*, xix. (1897), p. 20. The Obermittweida conglomerate among the mica-schists of Saxony is another well known example (Sauer, *Zeitsch. ges. Naturwiss.* lii. 1879, p. 706. J. Roth, *Sitzb. Akad. Wissensch.* Berlin, xxviii. 1883; 'Algem. u. Chem. Geologie.' ii. p. 428. Hughes, *Q. J. G. S.* xliv. 1888, p. 20).

[3] A voluminous series of papers has been published on the crystalline schists and gneisses of the Alps. Among these it is only possible here to cite a few: Zaccagna, *Bol. Com. Geol. Ital.* xviii. (1887), p. 346; V. Novarese, *op. cit.* 1896, No. 3; L. Mrazec, 'La protogine du Mont Blanc, &c.' Geneva, 1892; L. Duparc and Mrazec's "Massif du Mont Blanc," *Mem. Soc. Phys. Hist. Nat.* Geneva, xxxiii. (1898), 2nd and 3rd parts; Michel Lévy, *B. S. G. F.* 1879; J. W. Gregory, *Q. J. G. S.* l. (1894), p. 232; 'Livret Guide du Congres Géol. Internat,' Zurich, 1894.

Pre-Cambrian rocks rise to the surface in a number of detached areas in France, particularly in Brittany, the Cotentin, the central plateau,[1] Morvan, Cevennes, the Pyrenees, the Dauphiny Alps, and the Vosges. In Brittany they have been carefully studied by Dr. Barrois, who describes them as largely composed of mica-schists, passing often into gneiss and into quartzite, and including chlorite-schists, amphibolites, talcose and sericitic schists, serpentines, eclogites, and pyroxenites.[2] Extensive masses of granitoid and granulitic gneisses with mica-schists, amphibolites and other crystalline rocks form the foundation of the great central plateau of France. In Brittany, in the central plateau, as well as in other regions of France, thick masses of slates and phyllites have likewise been assigned to the pre-Cambrian series. In the Cotentin they are represented by the "Phyllades de St. Lô"—a thick series of hard lustrous slates or phyllites, among which some disputed organic remains have been found (pp. 877, 927). By other geologists, however, these phyllites are placed in the Cambrian system. They are named by Professor Barrois the "Brioverian system" (from Briovera, the ancient name of St. Lô), who separates them into three series: 1st, at the bottom the shales, phyllites, greywackes and cherts of St. Lô and Lamballe; 2nd, the shales, conglomerates and limestone of Gourin; and 3rd, the green flags of Néant. The base of the whole passes down insensibly into the crystalline schists below, and it is possible that these schists are really metamorphosed parts of the Brioverian series. In the absence of determinate fossils it cannot at present be decided whether the Brioverian are pre-Cambrian or Cambrian. They are certainly covered unconformably by unfossiliferous conglomerates and slates which are not improbably Cambrian.[3]

A large area of ancient crystalline schists extends southward from Dresden through Bavaria and Bohemia between the valley of the Danube and the headwaters of the Elbe. Two well-marked groups have been recognised—(*a*) red gneiss, containing pink orthoclase and a little white potash-mica, covered by (*b*) grey gneiss, containing white or grey felspar, and abundant dark magnesia-mica. According to Gümbel the former (called by him the Bojan gneiss) may be traced as a distinct formation associated with granite, but with very few other kinds of crystalline or schistose rocks, while the latter (termed the Hercynian gneiss) consists of gneiss with abundant interstratifications of many other schistose rocks, graphitic limestone, and serpentine. The Hercynian gneiss is overlain by mica-schists, above which comes a vast mass of argillaceous schists and shales. In Bohemia, these overlying crystalline clay-slates and schists ("Étage A" of Barrande) graduate upward into undoubted clastic rocks known as the Przibram Schists, unconformably over which come conglomerates and sandstones lying at the base of the fossiliferous series.[4] The same gradation occurs around the granulite tract of Saxony, where the outer schists may be merely metamorphosed Palæozoic sedimentary rocks.[5]

In the central and eastern Pyrenees some pre-Cambrian cores consist of masses of granitoid gneiss, with various chloritic and other schists and altered limestones. But

[1] The schists of this region are discussed by Mouret, *Bull. Carte. Géol. France*, No. 72 (1899).

[2] *Ann. Soc. Géol. Nord.* viii. x. xiv. xvi.

[3] *Proc. Geol. Assoc.* 1899, p. 105.

[4] For descriptions of the pre-Cambrian rocks of Saxony see Credner, *Z. D. G. G.* 1877, p. 757; 'Das Sächsische Granulitgebirge,' 1884. Lehmann, cited below. 'Erläuter. Geol. Specialkart," particularly sections Geringswalde, Geyer, Glauchau, Hohenstein, Penig, Rochlitz, Schwarzenberg, Waldheim, Wiesenthal. Bavaria and Bohemia: Gümbel, 'Geognostische Beschreibung des Ostbayerischen Grenzgebirges,' Gotha, 1868. Jokely, *Jahr. Geol. Reichsanstalt*, vi. p. 355; viii. pp. 1, 516. Kalkowsky, 'Die Gneissformation des Eulengebirges' (Habilitationschrift), Leipzig, 1878; *Neues Jahrb.* 1880 (i.) p. 29. F. Katzer, 'Geologie von Böhmen,' 1892. Baden: 'Erläuter. Geol. Specialkart.'

[5] Lehmann, 'Entstehung der altkrystallinischen Schiefergesteine,' 1884.

the most extensively developed rocks are various phyllites which here and there have assumed a gneissose character from contact metamorphism.[1] In Asturias and Galicia, Barrois has investigated a great series of schists regarded by him as pre-Cambrian, and divisible into two important groups—a lower, composed essentially of mica-schists, and an upper, consisting of green chloritous, amphibolitic, talcose, or micaceous schists, with subordinate bands of quartzite, serpentine, and cipollino.[2]

America.—In North America the pre-Cambrian rocks, which cover an area estimated at more than 2,000,000 square miles, from the Arctic Ocean southwards to the great lakes, have been studied in detail for a longer period than those of any other region, and in many respects they may serve as the type with which those of other parts of the globe may be compared.[3] They were first mapped and described by Logan and Murray in Canada, and were divided by these observers into two distinct divisions. The lower of these, named Laurentian from its extensive development among the Laurentide mountains, was described as consisting chiefly of coarse red, grey, and banded felspathic, hornblendic, micaceous, and pyroxenic gneisses with pegmatites, and included zones of limestone. The upper group, called Huronian from its exposures in the Lake Huron district, was recognised as being composed mainly of quartzites, felsites, diorites, diabases, syenites, various coarse and fine fragmental volcanic rocks (agglomerates and tuffs), clay-slates, and other bedded materials that pass into schists. Though the Huronian series was found along the line of junction to dip below the Laurentian, this position was believed to be due to disturbance, no doubt being

[1] Garrigou, *B. S. G. F.* i. (1873), p. 418; Caralp, 'Etudes Géologiques sur les Hauts massifs des Pyrénées centrales,' Toulouse, 1888.

[2] *Ann. Soc. Géol. Nord*, ii. (1882).

[3] Out of the large amount of literature which has grown up concerning the pre-Cambrian rocks of North America the following works may be cited: W. E. Logan, 'Geology of Canada,' 1863. *Annual Reports of the Geological Survey of Canada*, particularly Mr. Lawson's Report on Rainy Lake in the vol. for 1887; and papers by Dr. Barlow and by F. D. Adams in vol. viii. (1896), in *Journ. Geol.* i. (1893), p. 325, and in *Amer. Journ. Sci.* l. (1895), p. 58. *Geological and Natural History Survey of Minnesota*, vol. ii. Geology, by N. H. Winchell and W. Upham, 1888, and Annual Reports since 1887. *Geological Survey of Wisconsin*, Final Reports, vols. i. ii. iii. iv. by T. C. Chamberlin, R. D. Irving, C. E. Wright, E. T. Sweet, T. C. Brooks, &c. *Geological Survey of Michigan*, 1873 (T. Brooks), 1881, vol. iv. (C. Rominger), 1891-92, containing a sketch of the geology of the iron, gold, and copper districts by M. E. Wadsworth. *Second Geological Survey of Pennsylvania*, summary volume on Archæan Rocks by J. P. Lesley, 1892. *Annual Reports of the United States Geological Survey*, especially the 5th and 7th, containing memoirs by R. D. Irving, the 10th containing a joint memoir by R. D. Irving and C. R. Van Hise, the 14th with one by Messrs. Walcott and Iddings, the 16th and 21st with important essays by Van Hise, the 20th with papers by W. H. Weed and Pirsson; also Monograph v., on the copper-bearing rocks of Lake Superior by R. D. Irving; xxix. by Emerson; and xxxvi. by Morgan Clements and H. L. Smith; *B. U.S. G. S.* No. 23, T. C. Chamberlin and R. D. Irving; No. 157 by Hall; No. 159 by Emerson, R. Pumpelly and C. R. van Hise. *Amer. Journ. Sci.* xliii. (1892), p. 224. A. C. Lawson, *Bull. Geol. Soc. Amer.* i. (1890), pp. 163, 175; Bull. Geol. University, California, iii. No. 3, May 1902. A. Winchell, *B. Geol. Soc. Amer.* i. p. 357, ii. p. 85. N. H. Winchell, *Proc. Amer. Assoc.* xxxiii. (1885); *Amer. Geol.* xv. and xvi. (1895). J. D. Whitney and M. E. Wadsworth, "The Azoic System," *Bull. Mus. Comp. Zool.* Harvard, 1884. C. R. Van Hise, *Amer. Jour. Sci.* xli. (1891), p. 117; 16th *Ann. Rep. U.S. G. S.* 1896, pp. 573-874; 21st Do. 1901, pp. 305-434. R. Pumpelly and C. R. Van Hise, *Am. Jour. Sci.* xliii. (1892), p. 224. The literature of American pre-Cambrian geology has been exhaustively collected by C. R. Van Hise in *B. U.S. G. S.* No. 86, 'Correlation Papers Archæan and Algonkian,' 1892, and in a series of papers in *Journ. Geol.* vols. i. ii. iii. and iv. continued by C. K. Leith in subsequent volumes of the same journal.

entertained that the former series was the younger of the two. All these rocks lie beneath the undisturbed Potsdam sandstone of the Cambrian system.

Since the days of Logan, Murray, and Hunt, the great pioneers of American pre-Cambrian geology, the subject has been attacked by many able observers. The Geological Surveys of Canada and the United States, as well as those of some of the States of the Union, particularly Michigan, Wisconsin, and Minnesota, have examined the rocks over many hundred square miles, and have published voluminous reports concerning them. Owing to the great diversity of character which prevails among the oldest crystalline rocks of this wide region, and also because many of the districts lie far apart and have been worked out independently, considerable variety of nomenclature and diversity of view have arisen. At present it is hardly possible to reconcile these conflicting opinions, though there can be little doubt that before long a general concurrence will be arrived at regarding the main features of pre-Cambrian geology in this important region. Logan's original "Laurentian" series, often but incorrectly termed the "Fundamental complex," covers by much the largest area of all the North American pre-Cambrian formations, and presents the greatest persistence of lithological character. It consists of an intricate aggregation of crystalline rocks, which are sometimes acid and massive, as granite and syenite, but generally show more or less marked foliation, so as to pass into coarse or granitoid gneisses or gneissoid granites. With these are intimately mixed up masses and bands of diorites and gabbros, which usually have a foliated structure and pass into true schists, as well as various schists, the origin of which is less certain. There can hardly now be any doubt that these various rocks are of igneous origin; in many cases they can be seen actually to cut across and send veins into each other. They have subsequently been affected by intense dynamic action, whereby they have undergone internal rearrangments; their component minerals have often been crushed down, they have been squeezed into each other, crumpled up and compressed, and have acquired the general but unequal foliation which now characterises them. Logan thought he could recognise an older and coarser series, which he ranked as "Lower Laurentian," and a higher series, composed largely of anorthosites or norites, and including more varied and highly foliated gneisses, schists, slates, and limestones, which were regarded as "Upper Laurentian." It was originally supposed that the whole of the rocks were probably of sedimentary origin, but had undergone severe metamorphism.

More recent study of Logan's typical district and of other parts of Canada has led to a considerable modification of the views which he adopted. The igneous origin of the so-called Lower Laurentian gneisses is now generally conceded. The anorthosites or norites of the upper subdivision have likewise been shown to be enormous protrusions of eruptive material which have invaded the schistose rocks among which they lie. These latter rocks, known as the Grenville series of Ontario, include varieties of gneiss and other schists which have been closely examined by Professor Adams, who has determined by chemical analysis the similarity of their composition to that of altered sediments. They are interstratified with quartzites and limestones in such a way as to make their original sedimentary origin highly probable. These various rocks are so intimately mingled with the erupted gneisses of the so-called "Fundamental complex" that they cannot be separated in mapping. There appears to be reason to regard the Grenville series as a more highly altered condition of the so-called "Hastings series," near the city of Ottawa, which presents many points of lithological and stratigraphical resemblance to the "Huronian" rocks, originally mapped by Logan to the north and north-east of Lake Huron.[1] It thus appears that the Laurentian gneisses, instead of forming a

[1] F. D. Adams, *Neues. Jahrb.* Beilage Band viii. (1893); *Amer. Journ. Sci.* l. (1895), p. 58; iii. (1897), p. 173; *Ann. Rep. Geol. Surv. Canada*, Part i. vol. viii. (1896). A. P. Coleman, "The Huronian Question," *Amer. Geol.* xxix. (1902), p. 325. The anorthosites of Lake Superior are discussed by N. H. Winchell and A. C. Lawson, *Bull. Geol. Surv. Minnesota*, No. 8, 1893.

"fundamental complex" on which the oldest sedimentary formations repose, are really in part at least younger than these formations, and have been actually intruded into and through them. It was proposed by the United States Geological Survey to reserve the term "Archaean" for all the essentially igneous rocks that underlie the pre-Cambrian sedimentary formations, and to embrace these sedimentary formations under the general designation of "Algonkian." But we now know that the "Archaean" series includes various sedimentary intercalations, and that the "Algonkian" is actually pierced by portions of the "Archaean" masses. Some revision of the nomenclature is thus necessary. At present it is not definitely known how much of the so-called Laurentian or "fundamental complex" is older than the Huronian rocks.

In Canada and the Lake Superior region of the United States the following groups of pre-Cambrian formations have been recognised in descending order beneath the oldest Cambrian strata there developed.

Keweenawan (Nipigon of W. Ontario) consists of three main divisions, having a united thickness which varies up to 35,000, or according to Irving, even to 50,000 feet. At the base lies a band of gabbro. Above it comes the main group of the formation, consisting of a vast succession of lava-sheets which, in their under parts, become more interstratified with sandstones and conglomerates. The third group is composed of detrital material derived from the waste of the rocks below.[1] The Keweenawan lies unconformably on the Animikie series.

Animikie (Penokee, Upper Menominee, Upper Marquette), mainly a sedimentary series, consisting of a lower quartzite and an upper slate formation, with subordinate beds of siderite and ferruginous chert. An important unconformability at the base of these series extends over a wide area and, according to Lawson, marks a vast interval of time, separating the Huronian from all later periods.[2]

Upper Huronian (Upper Keewatin, Lower Menominee, Lower Marquette), mainly a sedimentary series comprising limestones, quartzites, conglomerates, slates, &c. These strata are pierced by granites or gneisses, and lie unconformably on the older members of the series with a conglomerate at the base.

Lower Huronian (Lower Keewatin) composed largely of green schists with recognisable sediments, among which are quartzites, sandstones, arkoses, and conglomerates, together with limestones and shales that pass into phyllites. Large bodies of volcanic rocks are included, consisting of greenstones and tuffs which have been altered into schists. An unconformability occurs at the base of this series.

Coutchiching, characteristic rather of the west than of the east, consists of quartz-biotite-schists and fine grey gneisses of remarkably uniform character. In the Eastern districts of Canada the Hastings and Grenville series above referred to are the oldest rocks to which a sedimentary origin can be assigned. They have been invaded by portions of the Laurentian gneisses, granites, and anorthosites.

Laurentian ("Fundamental complex"). The rocks comprised under this name may include the oldest masses of the continent. They are of eruptive character, and are certainly in part younger than the overlying formations below the "Eparchean interval."

In the east of the Canadian region a large development of sedimentary deposits underlies the Cambrian formations, and, mainly through the labours of Mr. G. F. Matthew, has been made to yield an interesting fauna. These rocks, which have been variously considered as pre-Cambrian and as Cambrian, occur in New Brunswick, Cape Breton, and Newfoundland. In the last named district they have been subdivided by Mr. Walcott as follows:

[1] C. R. Van Hise, *B. U.S. G. S. No. 86*, 1892; 16th *Ann. Rep. U.S. G. S.* 1896. In illustration of the differences of opinion among North American geologists as to the correlation of the pre-Cambrian rocks of the continent, see the series of papers by Professor N. H. Winchell in *Amer. Geol.* vols. xv. and xvi., published in 1895; A. B. Willmott, *Journ. Geol.* x. (1902), p. 67; A. C. Lawson, *Bull. Geol. Univ. California*, iii. No. 3, (1902), p. 51.

[2] "The Eparchean Interval," in the paper last cited.

Random reddish and grey sandstones, with some shales and conglomerates, perhaps	1000 feet
Signal Hill red and grey sandstones, with a thick conglomerate at the top	3120 ,,
Momable dark brown or blackish slates (St. John's), with obscure organic remains	2000 ,,
Torbay green, purple, pinkish, or red slates, in frequent alternations: forms supposed to be *Oldhamia*, found towards the top of the group	3300 ,,
Conception slate-conglomerate, slates (1650 feet) lying on diorites, quartzites, and jaspery bands and hard greenish slates (1300 feet)	2950 ,,
	12,370 feet

At the top of the Random group lies a thin band of conglomeratic limestone, which is taken by Mr. Walcott as the base of the Cambrian system.[1]

Far to the west, in the heart of the continent, pre-Cambrian rocks extend over a wide area in Montana (Belt Mountains), where they consist of shales and limestones, with some quartzite and sandstone at the base. They attain the great thickness of 12,000 feet, of which nearly 7000 feet are composed of shales in five principal groups, with two massive limestones, the lower of which (Newland Limestone) is 2000 feet and the higher (Helena) 2400 feet thick. In shales at a depth of 7700 feet from the top of the series four species of annelid trails have been found, with worm burrows and thousands of ill-preserved crustacean fragments that appear to be early forms of merostomata.[2] These strata are covered unconformably by others of Middle Cambrian age. Again, in the Grand Canyon of the Colorado, a remarkable series of strata, nearly 12,000 feet thick, unconformably underlies a Middle Cambrian formation. It differs considerably in lithological character from that of Montana, presenting a much less development of limestone and a great predominance of sandstones, and including an interstratified zone of basaltic lavas, with intercalated sandstones, 800 feet in thickness. Traces of organisms have been detected in the upper (Chuar) division of this series. One of these, a stromatopora-like form, was doubtfully referred by Dawson to *Cryptozoon*, though he thought it might not be really organic. Some objects like discinoid shells have been described under the name of *Chuaria*.[3]

From beneath the oldest sedimentary rocks, gneisses, and other crystalline masses like those of the eastern States and Canada rise to the surface in the mountain chains throughout the continent. Pre-Cambrian sediments appear in the Adirondack range.[4]

Africa.—Crystalline schists and gneisses, with granites and other massive crystalline rocks, cover a large part of this continent. They come to the surface in many wide districts from Egypt to the Cape. From the first cataract of the Nile they stretch eastwards into the Arabian mountains and the peninsula of Sinai. They form the rugged platform which, stretching southward from the Nubian Desert, has been overflowed by the lavas of Abyssinia, and supports the great line of old volcanoes, of which Kilimanjaro and Mount Kenia are the chief. Crossing German East Africa and the British territories they sweep through the western tracts of Matabele Land, the Transvaal, and Bechuanaland to the north of Cape Colony.[5] They range along the

[1] *Proc. Washington Acad. Sci.* i. (1900), p. 310. There is a difference of opinion between this geologist and Mr. W. G. Matthew as to the classification of these rocks. The latter classes as pre-Cambrian, under the name of "Etchiminian," the older sedimentary rocks below a certain sandstone which, he thinks, lies at or near the horizon of *Olenellus* (*Trans. New York Acad. Sci.* xiv. p. 103). Mr. Walcott, on the other hand, carries the Cambrian down to the top of the Random group, and regards the "Etchiminian terrane" as Lower Cambrian. The Etchiminian fossils are noticed *postea*, p. 931.

[2] C. D. Walcott, *Bull. Geol. Soc. Amer.* x. (1899), pp. 201, 235.

[3] C. D. Walcott, *op. cit.* pp. 215, 232.

[4] J. F. Kemp, *Proc. Amer. Assoc.* xlix. (1900), Address to Geological Section.

[5] E. Cohen, *Neues Jahrb.* 1874; A. Schenck, *Petermann Mittheil.* xxxiv. (1888), p. 225;

west coast at a greater or less distance from the sea, mounting inland into the great central plateau. Some portions of them have been described in detail as developed in the Congo basin.[1] They rise in isolated tracts of the Sahara and appear again in the core of the Atlas mountains.

India.—In India, the oldest known rocks are gneisses which underlie the most ancient Palæozoic formations, and appear to belong to two periods. The older or Bundelkund gneiss is covered unconformably by certain "transition" or "submetamorphic" rocks, which, as they approach the younger gneiss, become altered and intersected by granitic intrusions. The younger or peninsular gneiss is therefore believed to be a metamorphic series unconformable to the older gneiss. In the western Himalayan chain there are likewise two gneisses—a central gneiss, probably Archæan, and an upper gneiss formed by the metamorphism of older Palæozoic rocks into which it passes, and which lie unconformably on the older gneiss and contain abundant fragments derived from it.[2]

China.—Pre-Cambrian rocks are extensively developed in Northern China, forming the fundamental masses round and over which the later rocks have been laid down. According to Richthofen, the oldest portions of the series are mica-gneisses and gneiss-granites with hornblende-schists, mica-schists, &c., having an N.N.W. strike and steep inclination. Apparently of later date are some chlorite-gneisses and hornblende gneisses with intercalations of mica-gneiss and granulite, but without gneiss-granite, seen in north Tshili and north Shansi, and marked by a persistent W.S.W. and E.N.E. strike. These rocks are succeeded unconformably by a great series of groups which may belong to distinct periods. They consist of mica-schists, crystalline limestones, black quartzites, hornblende-schists, coarse conglomerates, and green schists. With some of these groups are associated granite, pegmatite, syenite, and diorite. The whole series underwent great plication and denudation before the deposition of the older Palæozoic formations (Sinisian).[3]

Japan.—The Abukuma plateau of Japan presents a copious development of amphibole- and biotite-granites, both massive and schistose, gneiss-mica-schist, biotite-schists with garnet or hornblende, titanite-amphibole-schists, quartz-schists, amphibole-picrite and other crystalline masses, which have been fully described by Professor Koto.[4]

Australasia.—In New Zealand crystalline schists cover an area of 8000 square miles. In the South Island the most ancient Palæozoic rocks are underlain by vast masses of crystalline foliated rocks traceable nearly continuously on the west side of the main watershed. The geological relations of these masses have not yet been satisfactorily defined, and it does not appear to be established whether any portions of them are undoubtedly pre-Cambrian. They are divided by Sir J. Hector into two series, of which the lower consists of gneiss, granite, &c., with an overlying mass of hornblendic, micaceous, and argillaceous schists (probably metamorphosed Devonian); while the upper consists of argillaceous slates and schists, which are regarded as probably altered Silurian or even Carboniferous rocks.[5] In Canterbury there is a central zone of micaceous, talcose, and graphitic schists, overlain by chlorite and hornblende-schists, and lastly by a quartzitic zone interleaved with schists.[6] Crystalline schists and gneisses form the rugged mountainous ground of south-western Otago. The centre of

W. Gibson, *Q. J. G. S.* xlviii. (1892), p. 420; *Trans. Fed. Inst. Min. Engin.* 1896. F. H. Hatch, *Q. J. G. S.* liv. (1898), p. 73.

[1] J. Cornet, *Ann. Soc. Belg. Géol.* xxiv. (1897), p. 25; *Bull. Soc. Belge Géol.* xi. (1899), p. 311.

[2] Medlicott and Blanford, 'Manual of Geology of India,' pp. xviii, xxvi, and Oldham in 2nd edit. of same work, chap. ii.

[3] Richthofen, 'China,' ii. 1882.

[4] *Journ. Coll. Sci. Imp. Univ.* Tokyo, v. (1893), Part iii.

[5] 'Handbook of New Zealand,' by J. Hector, M.D., Wellington, 1883.

[6] Haast's 'Geology of Canterbury,' p. 252.

this province is occupied by a broad band of gently inclined mica-schists and slates. These rocks are the main gold-bearing series of Otago.[1]

Rocks assigned to an Archæan age are believed to cover an area of perhaps 20,000 square miles in Australia. They consist of gneiss, mica-schist, chlorite, or talc-schists, hornblende-schists, quartzites, conglomerates, micaceous red mudstones, marble limestone, hæmatite, ilmenite, and graphite. They have not been definitely recognised in Victoria, New South Wales, Queensland, and the northern territory of South Australia, though some of the crystalline schists known in these regions may ultimately be referable to this part of the Geological Record. In South Australia they are developed on a large scale near Adelaide, and in the Mount Lofty range. At Ardrossan they are unconformably overlain by the Lower Cambrian Limestone. Archæan rocks appear in the Musgrave and Macdonnell ranges and in the Kimberley district of West Australia.[2] In Tasmania rocks assigned to the Archæan series cover large tracts on the west side of the island, and occur less abundantly in the north and east. They consist of gneiss, quartz-schists, mica-schists, talc-schists, chlorite-schists, siliceous conglomerates and breccias, with frequent subordinate bands of limestone, dolomite, serpentine, hæmatite, magnetite, and other minerals.[3]

PART II. PALÆOZOIC.

It has been shown in the foregoing pages that though the stratified pre-Cambrian rocks are generally separated by an unconformability from formations of later age, such a break does not always occur, and that in its absence, no sharp line of division can be drawn by way of upward limit to the pre-Cambrian series. It is obvious that the physical conditions of sedimentation underwent no universal interruption at the close of pre-Cambrian time, but that these conditions, having already been established long before the Cambrian period, were continued in some regions into that period without a break. Moreover, it has now been ascertained beyond doubt that plant and animal life had already appeared upon the earth during pre-Cambrian time. Hence the term Palæozoic, or Primary, which has hitherto been used to denote the older fossiliferous systems that terminate downward at the base of the Cambrian rocks is no longer strictly accurate, unless it is extended so as to include the very oldest strata in which organic remains have been found. Geologists have agreed to fix the base of the Cambrian system at the *Olenellus*-zone, already referred to. It is quite evident, however, that at any moment a new series of fossils may be discovered below that horizon, and it will then be matter for consideration whether such a series should be included in the Cambrian fauna or be made the palæontological basis for the designation of a still older geological system. In the present meagre state of our knowledge regarding these ancient rocks, it seems the most prudent course to take in the meantime the platform of the *Olenellus*-zone, which has now been recognised in many parts of the globe, as the Cambrian basement, and to fix there provisionally the downward limit of

[1] Hutton's 'Geology of Otago,' p. 31.

[2] Professor Edgeworth David, Presidential Address, *Proc. Linn. Soc. N. S. Wales*, viii. (1894), p. 548. For the notices of Australian geology on this and subsequent pages I am much indebted to the lucid summary presented in this Address.

[3] R. M. Johnston, 'Geology of Tasmania,' 1888, p. 16.

the Palaeozoic series of systems. That series will thus include all the older sedimentary formations from the bottom of the Cambrian to the top of the Permian system. The strata embraced under the comprehensive designation of Palaeozoic consist mainly of sandy and muddy sediments with occasional intercalated zones or thick masses of limestone. They bear witness for the most part to comparatively shallow water and the proximity of land. Their frequent alternations of sandstone, shale, conglomerate, and other detrital materials, their abundant rippled and suncracked surfaces, marked often with burrows and trails of worms, as well as the prevalent character of their organic remains, show that they must generally have been deposited in areas of slow subsidence, bordering continental or insular masses of land. Their limestones and cherts may point to accumulation in deeper and clearer water. From the character of the organisms preserved in them, the Palaeozoic rocks, as far as the present evidence goes, may be grouped into two main divisions—an older and a newer: the former, or Silurian facies (from the base of the Cambrian to the top of the Silurian system), distinguished more especially by the abundance of its graptolitic, trilobitic, and brachiopodous fauna, and by the absence of vertebrate remains, save from the uppermost formations; the latter, or Carboniferous facies (from the top of the Silurian to the top of the Permian system), marked by the number and variety of its fishes and amphibians, the absence of graptolites, the decreasing number of trilobites, and the increasing abundance of its cryptogamic terrestrial flora.

Section i. Cambrian.

§ 1. General Characters.

In those regions of the world where the relations of the pre-Cambrian to the oldest unmetamorphosed Palaeozoic rocks are most clearly exposed and have been most carefully studied, it is seldom that any conformable passage can be traced between these two great rock-groups, though, as already stated, occasional examples of such a gradation occur. More usually a marked unconformability and strong lithological contrast have been observed between the two series, the younger frequently abounding in pebbles derived from the waste of the older. Such a break points to the lapse of a vast interval of time during which the pre-Cambrian rocks, after suffering much crumpling and metamorphism, were ridged up into land and were then laid open to prolonged denudation. These changes seem to have been more especially prevalent in the northern part of the northern hemisphere. At all events, there is evidence of extensive upheaval of land in the north-west of Europe and across the northern tracts of North America and Northern China[1] prior to the deposit of the earliest

[1] The vast erosion of the pre-Palaeozoic land is nowhere more impressively shown than in Northern China, where, as Richthofen has pointed out, the oldest gneisses are surmounted by thousands of feet of sedimentary material (Sinisian formation), in the uppermost parts of which Primordial fossils are found. 'China,' vol. ii.

remaining portions of the Palaeozoic formations. These strata, indeed, were derived from the degradation of that northern land, the extent and height of which may be in some measure realised from the enormous piles of sedimentary rock which have been formed out of its waste. To this day, much of the land in the boreal tracts of the northern hemisphere still consists of pre-Cambrian gneiss. We cannot affirm that the primeval northern land was lofty; but, if it was not, it must have been subjected to repeated renewals of elevation, to compensate for the loss of height which it suffered in the denudation that provided material for the deep masses of Palaeozoic sedimentary rock.

The earliest connected suite of deposits in the Palaeozoic series received the name "Cambrian" from Sedgwick, who with great skill unravelled the stratigraphy of the most ancient sedimentary rocks of North Wales (Cambria). When the peculiar brachiopodous and trilobitic fauna of Murchison's Silurian system was found to descend into these rocks, the term Primordial Zone or Primordial Silurian was applied to them by Barrande in Bohemia. For many years, however, they yielded so few fossils that their place as a distinct section of the geological record was disputed. Eventually by the labours of Barrande in Bohemia; Hicks in South Wales; Brögger, Linnarsson, and others in Scandinavia; Schmidt in the Baltic provinces of Russia; Billings, Matthew, Walcott, and others in Canada and the United States, as well as various workers in other countries—such a distinctive fauna has been brought to light as serves to characterise a series of deposits at the base of the Palaeozoic formations. This assemblage of fossils, Barrande's first or Primordial fauna, is now by common consent more commonly known as Cambrian. The use of the terms Cambrian and Silurian will be more fully referred to in later pages.

ROCKS.—The rocks of the Cambrian system present considerable uniformity of lithological character over the globe. They consist of grey and reddish grits or greywackes, quartzites, and conglomerates, with shales, slates, phyllites, or schists, and sometimes thick masses of limestone. Their false-bedding, ripple-marks, and sun-cracks indicate deposit in shallow water and occasional exposure of littoral surfaces to desiccation. The limestones and cherts are doubtless the memorials of deeper seas where mechanical sediments ceased to be deposited. Nodules and layers of phosphate of lime are found among the shales and limestones both in Europe and in North America.[1] Sir A. C. Ramsay suggested that the non-fossiliferous red strata may have been laid down in inland basins, and he speculated upon the probability even of glacial action in Cambrian time in Britain.[2] As might be expected from their high antiquity, and consequent exposure to the terrestrial changes of a long succession of geological periods, Cambrian rocks are usually much disturbed. They

[1] See papers by H. Hedström, *Geol. Fören. Stockholm*, xviii. (1897), pp. 560-620, and authorities there cited; also J. G. Andersson, *Bull. Geol. Inst. Upsala*, ii. Part ii (1895), and *Geol. Fören. Stockholm*, xix. p. 245.

[2] *Q. J. G. S.* xxvii. (1871), p. 250; *Proc. Roy. Soc.* xxiii. (1874), p. 334; *Brit. Assoc.* 1880, Presidential Address.

have often been thrown into plications, dislocated, placed on end, cleaved and metamorphosed. In some regions they contain clear evidence of contemporaneous volcanic action. Thus in Wales they include towards their base an interesting group of felsitic and diabase-tuffs, and olivine diabase lavas, through which eruptive acid rocks (granite, quartz felsite, &c.) have risen.

LIFE.—Much interest necessarily attaches to Cambrian fossils, for excepting the few and obscure organic remains obtained from pre-Cambrian strata, they are the oldest assemblage of organisms yet known. They form no doubt only a meagre representation of the fauna of which they were once a living part. One of the first reflections which they suggest is that they present far too varied and highly organised a suite of organisms to allow us for a moment to suppose that they indicate the first fauna of our earth's surface. Unquestionably they must have had a long series of ancestors, though of these still earlier forms such slight traces have yet been recovered.[1] Thus, at the very outset of his study of stratigraphical geology, the observer is confronted with a proof of the imperfection of the geological record. When he begins the examination of the Cambrian fauna, so far as it has been preserved, he at once encounters further evidence of imperfection. Whole tribes of animals, which almost certainly were represented in Cambrian seas, have entirely disappeared, while those of which remains have been preserved belong to different and widely separated divisions of invertebrate life.

The prevailing absence of limestones from the Cambrian deposits of Western Europe, except in N.W. Scotland, is accompanied by a scarcity of the foraminifera, corals, and other calcareous organisms which abound in the limestones of the next great geological series.[2] The character of the general sandy and muddy sediment must have determined the distribution of life on the floor of the Cambrian sea in that region, and doubtless has also affected the extent of the final preservation of the organisms actually entombed. In North America, on the other hand, where thick sheets of Cambrian limestone occur, the conditions of sedimentation have been far more favourable for the preservation of organic forms; hence the known Cambrian fauna of this region exceeds in numerical value that of Europe.

The plants of the Cambrian period have been scarcely at all preserved. No vestige of any land plant of this age has yet been detected. That the sea then possessed its sea-weeds, can hardly be doubted, and various fucoid-like markings on slates and sandstones (*e.g.* the so-called fucoids of the "fucoid-beds" of N.W. Scotland, and of the "fucoidal sandstone" of Scandinavia) have been referred to the vegetable kingdom. The

[1] Richthofen has suggested that in China possibly some of the deep parts of his "Sinisian" formation (which in its higher parts yields Primordial fossils) may yet reveal traces of still older faunas.

[2] In the Baltic basin some bands of limestone occur in the comparatively thin series of Cambrian strata. In Scotland the Cambrian system includes some 1500 feet of dolomite and limestone.

genus *Eophyton*[1] from Sweden, *Phycodes* from the "Phycoidenschiefer" of the Fichtelgebirge and other forms from the Potsdam sandstone of North America, have been described as plants. There seems to be little doubt, however, that of these various markings some are tracks, probably of worms, others are worm-casts, while some are merely imitative wrinkles and markings of inorganic origin.[2] It is not certain that any of them are truly plants. Some branched filamentous forms found in the Cambrian limestone of Sardinia have been described as confervoid algæ.[3] What has been regarded as an undoubted organism occurs in abundance in the Cambrian rocks of the south-east of Ireland, and is named *Oldhamia* (Fig. 374). For many years it was considered to be a sertularian zoophyte, subsequently it was referred to the calcareous algæ; but its true grade seems still uncertain.[4]

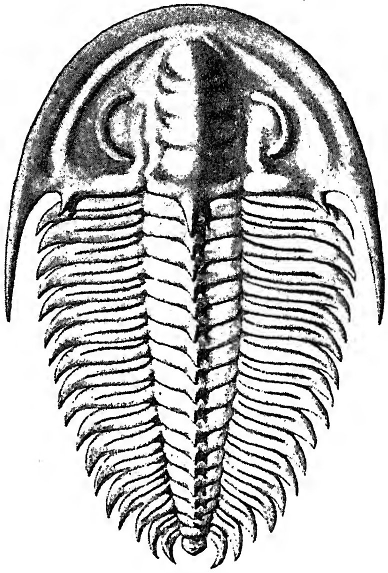

Fig. 372.—Olenellus (Holmia) Callavei, restored by Lapworth, the characteristic genus of the lowest Cambrian strata (½).

Among the animal organisms of the Cambrian rocks some of the simplest forms yet detected are radiolaria (Sphæroidea). Lithistid sponges are present in *Archæoscyphia* and *Nipterella*; and hexactinellids in *Protospongia*[5] (Fig. 374). No calcareous forms are yet known in this ancient formation. The hydrozoa appear chiefly in the earliest forms of the tribe of graptolites which played such an important part in Silurian time. *Dictyograptus* (*Dictyonema*) is one of the most characteristic fossils of the primordial zone of Scandinavia. It is found also in Central Europe, Britain and North America. The St. John group of New Brunswick, which is referred to the upper part of the Cambrian system, likewise contains representatives of the Dichograptidæ and Callograptidæ. Casts regarded as those left by medusæ on the soft mud by the sea-shore were noticed

[1] See G. J. Hinde, *Geol. Mag.* 1886, p. 337; the "fucoids" of the "fucoid-beds" of N.W. Scotland are undoubtedly worm-casts.

[2] See A. G. Nathorst's essay, "Nouvelles observations sur des traces d'Animaux, &c." 4to, Stockholm, 1886. See note, *postea*, p. 936.

[3] J. G. Bornemann, *Nov. Act. Acad. Cæs. Leop. Car.* lvi. 1891.

[4] Its claim to be considered organic has even been disputed, but from the manner in which it occurs on successive thin laminæ of deposit I cannot doubt that it is really of organic origin. The latest discussion of the subject by Professor Sollas will be found in *Q. J. G. S.* lvi. (1900), p. 273. He has no doubt of its organic origin, but cannot definitely say whether it was a plant or an animal.

[5] For a description of the character of this earliest sponge, see Sollas, *Q. J. G. S.* xxxvi. (1880), p. 362.

by Dr. Nathorst in 1881 as occurring in the Lower Cambrian rocks of Scandinavia. Since that time Mr. Walcott has brought to light a remarkable series of well-preserved casts in the Middle Cambrian formations of Alabama. Those in the lower subdivision are referred to two genera, *Medusina* and *Dactyloidites*, and those in the middle group to *Laotira* and *Brooksella*. The forms of these perishable organisms have been singularly well preserved in the fine sediment, and a series of casts of modern Medusæ in plaster of Paris has illustrated in a striking manner

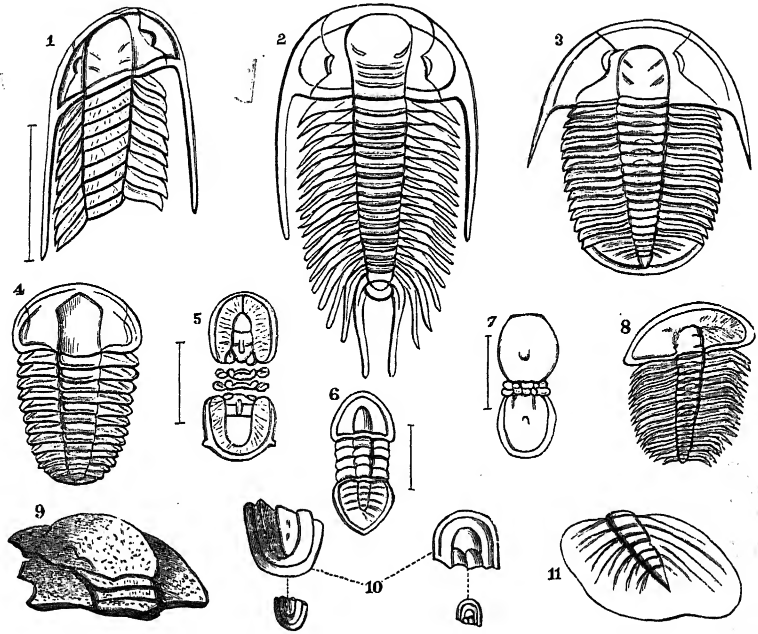

Fig. 373.—Group of Cambrian Trilobites.[1]

1, Olenus impar, Salt. (enlarged); 2, Paradoxides Davidis, Salt. ($\frac{1}{10}$); 3, Conocoryphe (?) Williamsoni, Belt.; 4, Ellipsocephalus Hoffi, Schloth.; 5, Agnostus trisectus? Salt. (enlarged); 6, Microdiscus sculptus, Hicks (enlarged); 7, Agnostus Barlowii, Belt. (enlarged); 8, Erinnys venulosa, Salt; 9, Plutonides Sedgwickii, Hicks; 10, Agnostus cambrensis, Hicks (and enlarged); 11, Dikelocephalus celticus, Salt.

the process of fossilisation.[2] The Actinozoa of the Cambrian period occur in a number of early types of corals which include the family of Archæocyathidæ (*Archæocyathus*,[3] *Ethmophyllum*, *Spirocyathus*, *Protopharetra*, &c.). The Echinodermata are represented by crinoids (*Dendrocrinus*?), cystideans (*Protocystites* or *Protocystis*, Fig. 374, *Eocystites* or *Eocystis*, *Macrocystella*, *Lichenoides*, *Trochocystites*, and other doubtful genera) and star-fishes (*Palæasterina*, Fig. 375). The crinoids reached their culmination in a

[1] Where not otherwise stated the figures are of the natural size.

[2] Walcott, *Mon. U.S. G. S.* No. xxx. (1898).

[3] Hinde, *Q. J. G. S.* xlv. (1889), p. 125.

variety of forms during Palæozoic time. Though still enormously abundant in individuals on some parts of the present sea-floor, they are but poorly represented there compared with the profusion of their genera and species in the earlier periods of the earth's history. Palæozoic crinoids were distinguished by the vaulted arrangement of accurately fitting plates, by which their viscera were completely enclosed, after the manner of the sea-urchins. The extinct class of cystideans, so named from the bag-like form in which the polygonal plates enclosing them are arranged, appear first in Cambrian strata and reach their highest development in

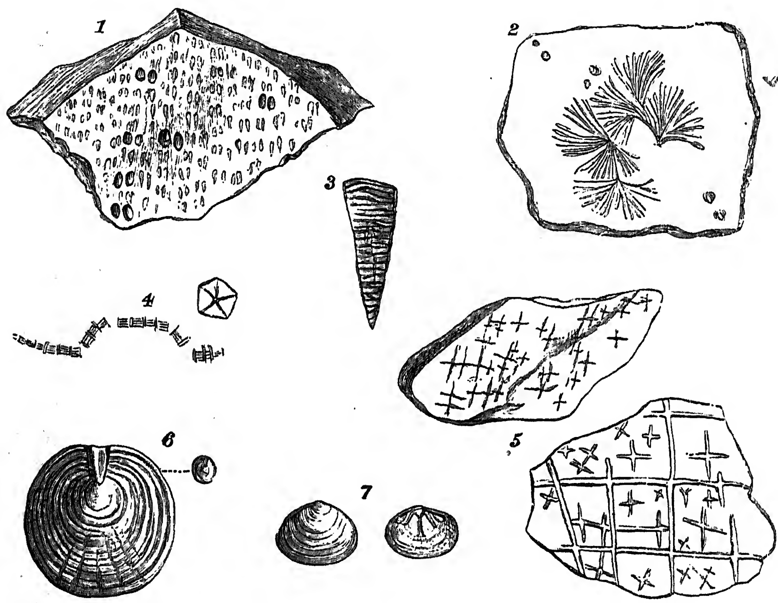

Fig. 374.—Group of Cambrian Fossils.

1, Arenicolites (Arenicola) didymus, Salt.; 2, Oldhamia antiqua, Forbes; 3, Hyolithes corrugatus, Salt.; 4, Protocystites (Protocystis) menevensis, Hicks (?); 5, Protospongia fenestrata, Salt. (and enlarged ½); 6, Discina pileolus, Hicks (and enlarged); 7, Obolella maculata, Hicks.

the lower half of the Silurian system, above which they rapidly diminish, until they disappear in the Carboniferous formations.

That Annelids existed during the Cambrian period is shown by their frequent trails and burrows (*Arenicolites* or *Arenicola*, Fig. 374, *Cruziana*, *Scolithus*, *Planolites*, &c.), and also possibly by the microscopic objects (conodonts) described by Pander from the Cambrian Blue Clay of Northern Russia, and believed by him to be fish-teeth, but regarded by Zittel and others as more probably those of free-swimming worms. But the most abundantly preserved forms of life are Crustacea, chiefly belonging to the extinct order of Trilobites (Figs. 372, 373). It is a suggestive fact that these organisms appear even here, as it were, on the very threshold of authentic biological history, to have reached their full structural develop-

ment. Some of them, indeed, were of dimensions scarcely ever afterwards equalled, and already presented great variety of form. Individuals of the species *Paradoxides Davidis* are sometimes nearly two feet long. But with these giants were mingled other types of diminutive size. It is noteworthy also, as Dr. Hicks has pointed out, that while the trilobites had attained their maximum size at this early period, they were represented by genera indicative of almost every stage of development,

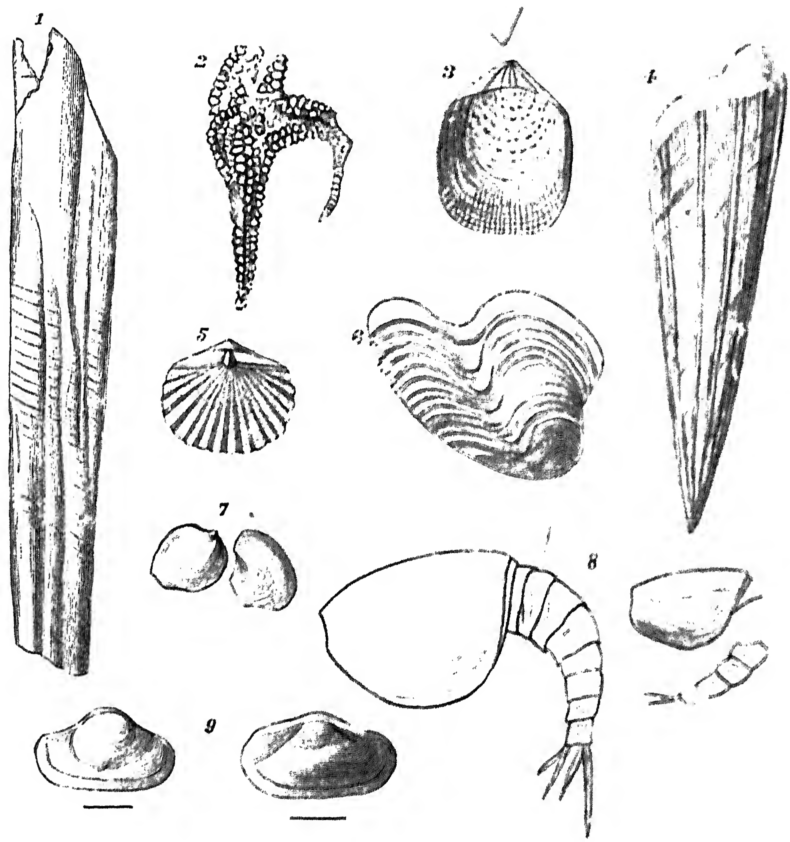

Fig. 375. Group of Cambrian Fossils.

1, Orthoceras? sericeum, Salt.; 2, Palaeasterina ramseyensis, Hicks; 3, Lingulella Davisii, M'Coy; 4, Conularia Homfrayi, Salt.; 5, Orthis Carausii, Salt.; 6, Bellerophon arfonensis, Salt.; 7, Palaearca Hopkinsoni, Hicks; 8, Hymenocaris vermicauda, Salt. (and enlarged); 9, Ctenodonta cambriensis, Hicks (enlarged).

"from the little *Agnostus* with two rings in the thorax, and *Microdiscus* with four, to *Erinnys* with twenty-four." *Conocoryphe*, *Agnostus*, *Olenellus*, *Paradoxides*, *Olenus*, and many other Cambrian trilobites appear to be without eyes.[1] In other genera (*Arionellus* [*Agraulos*], *Ellipsocephalus*,

[1] The recent researches of Lindström on the visual organs of trilobites (*K. Svensk. Vet.*

&c.) the eyes are so imperfectly shown that they were long unrecognised. With these forms were associated others having large eyes.[1] In the lower portions of the system the genera *Olenellus* (Fig. 372), *Olenelloides*, and *Holmia* are specially distinctive. Other characteristic Cambrian genera (Fig. 373) besides those already mentioned are *Plutonides*, *Anomocare*, *Ptychoparia*, *Solenopleura*, *Dikelocephalus*, *Olenus*, *Parabolina*, *Peltura*, *Eurycare*, *Sphaerophthalmus*, *Olenoides*, *Liostracus*, and *Angelenus*. Phyllocarid crustaceans likewise occur (*Hymenocaris*, Fig. 375, *Lingulocaris*), and there are representatives of the ostracods (*Primitia*, *Entomidella*).

In striking contrast to the thoroughly Palaeozoic and long extinct order of trilobites, the Brachiopods appear in numerous genera of the simple non-articulated forms which are still familiar in the living world. Of the four orders into which they are divided, the first (Atremata) is well represented by *Iphidea* (*Paterina*), *Obolus*, *Obolella* (Fig. 374), *Rhinobolus*, *Lingulella* (Fig. 375), and *Lingulepis*. The Neotremata muster largely in the genera *Acrotreta*, *Acrothele*, *Linnarssonia*, *Discinopsis*, *Trematobolus*, and *Discinolepis*. The articulate orders were likewise represented: the Protremata by *Kutorgina*, *Billingsella*, *Leptella*, *Orthis*; the Telotremata by primitive forms of *Rhynchonella*.

True mollusks were likewise present in the Cambrian seas, though their remains have only been sparingly preserved. The Lamellibranchs or pelecypods (Fig. 375) appear to be represented by *Modioloides* and other genera, perhaps also by *Fordilla*, which if not a crustacean like *Estheria* is the oldest known bivalve. The Gasteropods have been more abundantly preserved. They include the archaic *Scenella* (the earliest limpets), *Stenotheca*, *Platyceras*, *Rhaphistoma*, *Pleurotomaria*, *Ophileta*, *Maclurea*, *Trochonema*, and *Subulites*. The Pteropods may be represented by species of *Torellella*, *Hyolithellus*, *Salterella*, *Coleolus*, *Coleoloides*, and *Hyolithes* (Fig. 374). Two genera of nautiloid Cephalopods, *Orthoceras* (Fig. 375) and *Cyrtoceras*, have been described from Upper Cambrian (Tremadoc) strata, but doubt has been cast upon some alleged Cambrian forms.

Taking palaeontological characters as a guide in classification, and especially the distribution of the trilobites, geologists have grouped the Cambrian rocks in three divisions—the lower or Olenellus group, the middle or Paradoxidian, and the upper or Olenidian.

§ 2. Local Development.

Britain.[2]—The area of Britain in which the fullest development of the oldest known Palaeozoic rocks has yet been found is the principality of Wales. The rocks are there

Akad. xxxiv. 1901) indicate that the eye-like ridge which occurs in many genera was not a true eye.

[1] *Q. J. G. S.* xxviii. p. 174.

[2] See Sedgwick's Memoirs in *Q. J. G. S.* vols. i. ii. iv. viii., and his 'Synopsis of the Classification of the British Palaeozoic Rocks,' 4to, 1855; Murchison's 'Silurian System' and 'Siluria'; Salter's 'Cat. of Cambrian and Silurian Fossils,' with preface by Sedgwick, 1873; Ramsay's 'North Wales,' *Geological Survey Memoirs*, vol. iii.; and papers by Salter,

of great thickness (12,000 feet or more), they have yielded a fauna which, though somewhat scanty, is sufficient for purposes of stratigraphical correlation, and they possess additional importance from the fact that they were the first strata of such antiquity to be worked out stratigraphically and paleontologically. As already stated, they were called Cambrian by Sedgwick, from their extensive development in North Wales (Cambria), where he originally studied them. Their true base is nowhere seen. Professor Hughes, Dr. Hicks, Professor Bonney and others believe that a conglomerate and grit generally mark the base of the Cambrian series.[1] According to Sir A. C. Ramsay, on the other hand, the base of the Cambrian series is either concealed by overlying formations or by the metamorphism which, in his opinion, has converted portions of the Cambrian series into various crystalline rocks. Both in Pembrokeshire and Carnarvonshire the lowest visible slates, shales, and sandstones are interstratified with and pass down into a volcanic series (felsites, diabases, and tuffs), the base of which has not been found. In certain localities, as in Anglesey, Cambrian strata are seen to lie unconformably on pre-Cambrian schists, and there not only the basement volcanic group but some of the lowest members of the fossiliferous series are wanting. There is then not only an unconformable junction, but an overlap.

Starting from the volcanic group at the base, the geologist can trace an upward succession through thousands of feet of grits and slates into the Silurian system. Considerable diversity of opinion has existed as to the line where the upper limit of the Cambrian division should be drawn. Murchison contended that this line should be placed below strata where a trilobitic and brachiopodous fauna begins, and that these strata cannot be separated from the overlying Silurian system. He therefore included as Cambrian only the barren grits and slates of Harlech, Llanberis, and the Longmynd. Sedgwick, on the other hand, insisted on carrying the line up to the base of the Upper Silurian rocks. He thus left these rocks as alone constituting the Silurian system, and massed all the Lower Silurian rocks in his Cambrian system. Murchison worked out the stratigraphical order of succession from above, chiefly by help of organic remains. He advanced from where the superposition of the rocks is clear and undoubted, and for the first time in the history of geology, ascertained that the "Transition rocks" of the older geologists could be arranged into zones by means of characteristic fossils, as satisfactorily as the Secondary formations had been classified in a similar manner by William Smith. Year by year, as he found his Silurian types of life descend farther and farther into lower deposits, he pushed backward the limits of his Silurian system. In this he was supported by the general consent of geologists and paleontologists all over the world. Sedgwick, on the other hand, attacked the problem rather from the side of stratigraphy and geological structure. Though he had collected fossils from many of the rocks of which he had made out the true order of succession in North Wales, he allowed them to lie for years unexamined. Meanwhile Murchison had studied the prolongations of some of the same rocks into South Wales, and had obtained from them the copious suite of organic remains which characterised his Lower Silurian formations. Similar fossils were found abundantly on the continent of Europe and in America. Naturally the classification proposed by Murchison was generally adopted. As he included in his Silurian system the oldest rocks then known to contain a distinctive fauna of trilobites and brachiopods, the earliest fossiliferous rocks were everywhere classed as Silurian. The name Cambrian was regarded by geologists of other countries

Harkness, Hicks, Hughes, Lapworth, Groom, and others in the *Q. J. G. S.* and *Geol. Mag.*, to some of which reference is made below. J. E. Marr, in his 'Classification of the Cambrian and Silurian Rocks,' gives a bibliography of the subject up to 1883. The geographical extension and development of the Cambrian system over the Old and New Worlds is discussed by F. Frech, *Compt. rend. Congrès Géol. Internat.* St. Petersbourg (1899), p. 127.

[1] *Q. J. G. S.* xxxiv. p. 144; xl. (1884), p. 187. For references to the literature of the subject see the same Journal, xlvii. (1891), Ann. Address, p. 90 *seq.*

as the designation of a British series of more ancient deposits not characterised by peculiar organic remains, and therefore not capable of being elsewhere satisfactorily recognised. As above stated, Barrande, investigating the most ancient fossiliferous rocks of Bohemia, distinguished by the name of the "Primordial Zone" a group of strata forming the lowest member of the Silurian system, and containing a peculiar and characteristic suite of trilobites. Murchison adopted the term, grouping under it the lowest dark slates which in Wales and the border English counties contained some of the same early forms of life.

Subsequent investigations, by the late Mr. Salter and Dr. Hicks, brought to light, from the Primordial rocks of Wales, a much more numerous fauna than they were supposed to possess, and one in some degree distinct from that in the undoubted Lower Silurian rocks. Thus the question of the proper base of the Silurian system was re-opened, and much controversy arose as to the respective limits and relative stratigraphical value of the formations to be included under the designations Cambrian and Silurian. No such marked break, either palæontological or stratigraphical, had been found as to afford a clear line of division between two distinct "systems." Those who followed Murchison contended that even if the line of division were drawn at the upper limits reached by the primordial fauna, the Cambrian could not be considered to be a system as well defined and important as the Silurian, but that it ought rather to be regarded as the lower member of one great system comprising the primordial, and the second and third faunas, so admirably worked out by Barrande in Bohemia. To this system they maintained that the name Silurian, in accordance with priority and justice, should be assigned. Unfortunately a disagreement, which was not settled during the lifetime of Sedgwick and Murchison, bequeathed a dispute in which personal feeling played a large part. And though the fires of controversy have died out, it cannot be said that the questions in debate have been left on a satisfactory footing. There was a tendency towards a general agreement that the name Cambrian should be assigned to the strata containing Barrande's primordial fauna as far up as the top of the Tremadoc slates of Wales, when in 1879 Professor Lapworth proposed, as a compromise between the two views, that the lower half of Murchison's Silurian system, which Sedgwick had claimed as Cambrian, should be detached from both and erected into a distinct system under the name "Ordovician," the term "Silurian" being restricted to the uppermost formations of the series. This proposal, which was honestly intended to obviate confusion and to promote the progress of the science, was, in my opinion, especially unjust to Murchison. The division of "Lower Silurian" had the claim not only of priority, but of having had its component members defined by the author of the Silurian system in the early years of his investigation, and accepted by geologists all over the world. The primordial fauna which Barrande had shown to underlie the Lower Silurian rocks of Bohemia was hardly known to exist in Britain during Murchison's life, and certainly was not then ascertained to have the stratigraphical significance and wide geographical diffusion which have now been proved. It had come to be universally admitted that this fauna marks a distinct section of the geological record to which by common consent the name Cambrian had now been appropriated. The upper limit of this fauna having been generally recognised, it was not a question of fact but of nomenclature which was involved. To wipe out Murchison's accepted designation from half of the system which he was the first to define and describe, is a change quite unwarranted by any discoveries that have been made since his time. On the plea of "convenience" the term Silurian has by some writers been removed even from the remaining portion of the original system of Murchison, whose designation, so long one of the classic terms in stratigraphy, is thus expunged from the geological record. It is hardly possible to protest too strongly against this procedure.

These changes of nomenclature are unjustifiable even on the plea of convenience. If confusion has arisen in the use of terms, it should be removed in some less drastic fashion than by excising terms which have become inseparably interwoven with geological

literature. The changes, moreover, are retrograde in character and contrary to palæontological evidence furnished by the rocks themselves. In previous editions of this text-book I have contended that the most natural and logical classification is to group Barrande's three faunas as one system, which in accordance with the laws of priority and obvious justice should be called Silurian. The palæontological reasons for this arrangement were so cogent to Murchison's mind that he strenuously insisted on the unity of his "Silurian system." Since then the arguments that appealed so forcibly to his mind have been greatly strengthened by the continued advance of our knowledge, and in no respect more than by the researches of Professor Lapworth himself. That graptolites are organisms thoroughly typical of his Silurian system was fully recognised by Murchison,[1] but he was unaware how valuable they would become as indications of life-zones throughout the whole of that system from bottom to top, and how in this way by fresh detailed proof they would serve to link the whole of the sedimentary deposits in which they occur as the records of one great biological era, at the end of which they disappeared.[2]

After the first edition of this work was written, in which the future merging of Cambrian and Silurian into one great system was regarded as probable, the father of French stratigraphical geology, the late distinguished Hebert, thus expressed himself: "I adopt the opinion of M. Barrande, based as it was on such thorough and prolonged research, that there is one common character in his three first faunas which unites them into one great whole. To these faunas and the beds containing them I assign the name Silurian, because the Silurian fauna was the first to be determined; and, further, I am of opinion that the Cambrian group ought not to appear in our nomenclature as of equal rank with the Silurian group, of which it is merely a subdivision."[3] In the same year F. Schmidt, so widely known for his life-long labours among the older palæozoic rocks of the Baltic provinces of Russia, expressed the same opinion, remarking that he would prefer to regard the Cambrian as only part of one system extending up to the overlying unconformable Devonian rocks.[4] This classification has been adopted with modifications. The International Geological Congress published in 1897 a scheme of geological chronography by Professor Renevier, in which the whole of the formations in question were grouped under the name "Silurique," the lowest of the three groups into which these formations had long been divided being termed Cambrian, the middle, as proposed by Lapworth, Ordovician, and the uppermost Silurian. The obvious objection to the use of "Silurique" for the whole and "Silurian" for only the upper member appears fatal to the adoption of this arrangement. This objection is met by Professor De Lapparent, who classes as Silurian the whole of the formations from the base of the Cambrian up to the bottom of the Devonian series, retaining Cambrian for the lowest and Ordovician for the middle subdivision, and proposing the term "Gothlandian" for the uppermost. Such an arrangement is logically sound, and might be adopted if it did not involve so serious an alteration of the nomenclature in general use. It will not, however, satisfy the followers of Sedgwick to see their master's "system" placed as the lowest member of the Silurian formations; nor will it remove from the minds of those who are loyal to the memory of Murchison the apprehension that the removal of

[1] Thus in chap. iii. of 'Siluria' he remarks that "wherever graptolites are found they clearly mark the rock to be Silurian": and again, "the mere presence of a graptolite will at once decide that the enclosing rock is Silurian."

[2] M. Delgado, the distinguished Director of the Geological Survey of Portugal, has recently reaffirmed and supported Murchison's dictum, "Nous arrivons à la conclusion que les graptolites caractérisent exclusivement le système Silurique. . . . On doit par consequent considérer commes Siluriennes toutes les couches où paraissent ces Hydrozoaires" (*Comm. Direc. Serv. Geol. Portugal*, iv. Fasc. 2 (1901), p. 227).

[3] *B. S. G. F.* xi. (1882), p. 34.

[4] *Q. J. G. S.* xxxviii. (1882), p. 515.

the landmarks set up by him may only be the prelude (already actually to a slight extent realised) to the dropping of his name Silurian from the rocks which he was the first to investigate and describe. For these reasons I prefer to retain the classification which has hitherto been given in this text-book, adopting Sedgwick's name Cambrian for the rocks containing the first fauna of Barrande, and Murchison's terms "Lower Silurian" and "Upper Silurian" for those in which the second and third faunas are preserved.[1]

The Cambrian rocks of Britain vary widely in mineralogical composition, thickness, and area of exposure in the different districts where they rise to the surface. In North Wales, where they cover the widest extent of ground, they consist of purple, reddish-grey, green, and black slates, grits, sandstones, and conglomerates, with a volcanic group at the bottom, the whole attaining a thickness of probably more than 12,000 feet. In Western England this enormous mass of sedimentary material has dwindled down to a fourth or less, consisting at the base of quartzite and sandstone, and in the upper part of shales. In the East of Ireland, rocks assigned to the Cambrian system resemble on the whole the Welsh type. In the north-west of Scotland, on the other hand, the Cambrian strata, about 2000 feet visible, consist of quartzites below, graduating upwards into massive limestones. The following grouping of the British Cambrian rocks has been made :—

	Wales (ranging up to 12,000 feet or more).	Western England (about 3000 feet).	N. W. Scotland (at least 2000 feet).
Upper or Olenus series.	Tremadoc Slates. Lingula Flags. (*Lingulella*, *Olenus*, &c.)	Shineton Shales (*Dictyograptus* [*Dictyonema*] *Olenus*, &c.)	A thick mass of dolomite and limestone, with *Archæocyathus*, *Maclurea*, *Ophileta*, *Murchisonia*, *Orthoceras*, and vast quantities of annelid castings.
Middle or Paradoxides series.	Menevian Group (*Paradoxides*.	Conglomerates and limestones (Comley) with *Paradoxides*, &c.	
Lower or Olenellus series.	Harlech and Llanberis group and basement volcanic rocks ("Pebidian" of Hicks), bottom not seen.	Thin quartzite passing up into green flags, grits, shales, and sandstone (Comley Sandstone) containing *Olenellus*.	Shales with *Olenellus*, *Salterella*. Quartzites, with annelid burrows.

LOWER.[2]—In South Pembrokeshire the lowest visible Cambrian rocks are of volcanic origin. They consist of fine tuffs, and silky schists with sheets of olivine-diabase and andesite, and intrusive quartz-porphyries.[3] It is this volcanic group which the late Dr. Hicks proposed to class as a pre-Cambrian formation under the name of "Pebidian" (p. 896). In Carnarvonshire the Llanberis Slates, which form the lowest member of the Cambrian sedimentary series, are interleaved at their base with bands of volcanic tuffs and rest upon a mass of quartz-felsite, which is the lowest rock visible in the district.[4]

The Olenellus-zone, the characteristic palæontological feature of the lower Cambrian

[1] The reader who would peruse a weighty and dispassionate examination of this disputed question in geological nomenclature should turn to the essay by the late venerable Professor J. D. Dana on "Sedgwick and Murchison; Cambrian and Silurian" (*Amer. Journ. Sci.* xxxix. 1890, p. 167). With the conclusions of his examination of the whole subject I most thoroughly agree.

[2] The chief authority on the fossils of the Lower Cambrian rocks is the monograph by C. D. Walcott, "The Fauna of the Lower Cambrian or *Olenellus*-zone," published in the *10th Ann. Rep. U.S. Geol. Surv.* (1890). This work contains figures and descriptions of this the oldest known distinct assemblage of organisms, and gives a bibliography of the subject up to the year of publication. Some of the other more important memoirs will be cited in subsequent pages.

[3] *Q. J. G. S.* xxxix. (1883), p. 294. C. Lloyd Morgan, *op. cit.* xlvi. (1890), p. 241.

[4] A. G., *op. cit.* xlvii. (1891), Presidential Address, p. 90, and authorities there cited.

group, has not yet been certainly established in Wales.[1] It was first detected in the British Isles by Professor Lapworth, who in 1885 found fragments of *Olenellus* on the flanks of Caer Caradoc in Shropshire, associated with *Kutorgina cingulata, Linnarssonia sagittalis, Hyolithellus* and *Ellipsocephalus*.[2] It has been found by the officers of the Geological Survey in the west of Ross-shire, where the following lower Cambrian strata may be traced in a narrow strip of country for a distance of more than 100 miles :[3]—

Base of Durness limestones with *Salterella*.
Band of quartzite and grit (Serpulite grit) with abundant *Salterella Maccullochii*, and occasional thin shales with *Olenellus*.
Calcareous and dolomitic shales ("Fucoid beds") with numerous worm-casts usually flattened and resembling fucoidal impressions. *Olenellus* occurs in bands of dark blue shale.
Quartzites, in two divisions, the upper crowded with worm-burrows, the lower becoming pebbly at the base and resting unconformably on pre-Cambrian (Torridonian or Lewisian) rocks.

The discovery of the *Olenellus*-zone in this region has given a definite geological horizon from which to work out the stratigraphical succession above and below. It has conclusively proved that the Torridon Sandstone, formerly classed as Cambrian, must be relegated to the pre-Cambrian series (p. 890). Above the quartzite and shales which include the *Olenellus*-zone there lies a series of dolomites and limestones, divisible lithologically into seven groups with an aggregate thickness of about 1500 feet. Their original upper limit, however, cannot now be ascertained, for it has been concealed by the great dislocations which have so complicated the structure of that region (see Figs. 344, 369). We cannot tell what additional thickness of limestone may have been accumulated in the north-west at the time when only mud, silt, and sand were deposited over the southern parts of the British area, nor by what kind of sediment the limestones were succeeded. The limestones (now chiefly in the form of dolomite) are most fully developed around Durness in the extreme north-west of Sutherland, where they have yielded a large number of fossils. The facies of these fossils, however, is so peculiar that it has not yet been possible by their means to correlate the rocks containing them with the Cambrian formations of Wales. The limestones are so crowded with worm-casts that, as Mr. Peach has pointed out, nearly every particle of their mass must have passed through the intestines of worms. Hence they are obviously of detrital origin, and were probably formed in chief part by small pelagic animals. Only one coral has been found in them. The most abundant fossils are nautiloid cephalopods (*Orthoceras, Piloceras, Lituites*); next in number are gasteropods (chiefly *Maclurea* and *Pleurotomaria*), while the lamellibranchs and brachiopods come last. The bivalves have their valves still united, and the lamellibranchs retain the positions in which they lived. "All the specimens show that every open space into which the calcareous mud could gain access and the worms could crawl, is traversed by worm-casts. In the case of the *Orthoceratites*, they seem to have lain long enough uncovered by sediment to allow the septa to be dissolved away from the siphuncles which they held in place; many of these siphuncles are now found isolated." Sponges of the genus *Calathium* are scattered through the calcareous sediment, and likewise the doubtful but characteristic Cambrian forms, known as *Archæocyathus* which, once referred to the sponges, are now thought to be more probably corals. The general assemblage of fossils, as was originally pointed out by Salter, is of a distinctly North American type, and does not resemble that found in the slates, flags, and grits of Wales. The conditions of deposit must have been so entirely different that a great contrast in the organisms of the two areas of sedimentation could not but occur.

[1] Dr. Hicks believed that it exists there, *Geol. Mag.* 1892, p. 21.

[2] Lapworth, *Geol. Mag.* 1888, p. 484; 1891, p. 529.

[3] *Brit. Assoc. Rep.* 1891, p. 633. Peach and Horne, *Q. J. G. S.* xlviii. (1892), p. 227; l. (1894), p. 661.

Whether or not the contrast further arose from some geographical cause, such as a land barrier that completely separated the areas, remains uncertain. The Durness limestones, as regards their fossil contents and lithological character, may be compared with the Potsdam sandstone and Calciferous group of the United States and Canada. They represent the Middle and Upper Cambrian, possibly part of the Lower Silurian formations.[1]

MIDDLE.—This group appears to be most fully developed in South Wales, where it was first studied by Hicks, and found to yield a number of characteristic fossils. He has divided it into two groups, the Solva below and Menevian above. From the lower group a number of trilobites, including the typical genus *Paradoxides*, have been obtained, also *Plutonides*, *Microdiscus*, *Agnostus*, *Conocoryphe*. There occur likewise annelides (*Arenicolites*), brachiopods (*Discina*, *Lingulella*), pteropods (*Hyolithes*), and a sponge (*Protospongia*).

The name Menevian was proposed by Salter and Hicks for a series of sandstones and shales, with dark-blue slates, flags, and grey grits, which are seen near St. David's (Menevia), where they attain a depth of about 600 feet. They pass conformably into the Lower, and also into the Upper group. They have yielded upwards of 50 species of fossils, among which trilobites are specially prominent. *Paradoxides* is the typical genus, while *Agnostus*, *Anopolenus*, *Erinnys*, and *Conocoryphe* are of frequent occurrence. Sponges (*Protospongia*) and annelid tracks likewise occur. The brachiopods are represented by the genera *Discina*, *Lingulella*, *Obolella*, and *Orthis*; and the pteropods by *Cyrtotheca* and *Hyolithes*. An entomostracean (*Entomis*) and cystidean (*Protocystites*) have also been met with.

UPPER.—This highest section of the system has for a long time been divided in Wales into two well-marked groups of strata, the Lingula Flags below and the Tremadoc Slates above. The latter division contains a fauna of a mixed or transitional character. While it still displays a number of Primordial forms it includes so many Silurian types that, on palæontological grounds, it might be more appropriately placed at the base of the Silurian system. But it has so long been taken as the highest member of the Cambrian formations that it may perhaps be most conveniently retained in this place. As already stated, the characteristic palæontological feature of the Upper Cambrian strata is the prevalence of trilobites of the genus *Olenus*.

Lingula Flags.—These strata, consisting of bluish and black slates and flags, with bands of grey flags and sandstones, attain in some parts of Wales a thickness of more than 5000 feet. They received their name from the vast numbers of a lingula (*Lingulella Davisii*) in some of their layers. They rest conformably upon, and pass down into, the Menevian group below them, and likewise graduate into the Tremadoc group above. They are distinguished by a characteristic suite of organic remains. The trilobites include the genera *Olenus*, *Agnostus*, *Conocoryphe*, and *Dikelocephalus*. Early forms of phyllocarids (*Hymenocaris*) and gasteropods (*Bellerophon*) occur in these strata. The brachiopods include species of *Lingulella* (*L. Davisii*), *Discina*, *Obolella*, *Kutorgina*, and *Orthis*. The pteropods are represented by species of *Hyolithes*. Several annelides (*Cruziana*) and polyzoa (*Fenestella*) likewise occur.

A subdivision of the Lingula Flags into three sub-groups was proposed by Mr. T. Belt, in descending order as follows:[2]—

3. Dolgelly slates, about 600 feet, well seen at Dolgelly, consist of soft and hard blue slates and contain *Protospongia*, *Lingulella*, *Orthis lenticularis*, *Peltura scarabæoides*, *Parabolina spinulosa*, *Agnostus trisectus*, *Conocoryphe abdita*.
2. Ffestiniog flags, about 2000 feet, well seen at Ffestiniog, consist of hard sandy micaceous flagstones, and have yielded *Lingulella Davisii*, *Olenus micrurus*, *Hymenocaris vermicauda*, *Bellerophon cambrensis*.
1. Maentwrog flags and slates, about 2500 feet, best seen at Maentwrog in Merionethshire, consist of grey and yellow flagstones, and grey, blue and black

[1] B. N. Peach, *Q. J. G. S.* xliv. (1888), p. 407.

[2] *Geol. Mag.* (1867), p. 538.

slates, and contain among their somewhat scanty fossils *Olenus cataractes*, *O. gibbosus*, *Agnostus princeps* (*pisiformis*), *A. nodosus*.

Tremadoc Slates.—This name was given by Sedgwick to a group of dark grey slates, about 1000 feet thick, found near Tremadoc in Carnarvonshire, and traceable thence to Dolgelly in Merionethshire, and reappearing beyond the eastern side of Wales at the Wrekin, in Shropshire.[1] Their importance as a geological formation was not recognised until the discovery in them of a remarkably abundant and varied fauna, which includes early forms of crinoids, star-fishes, lamellibranchs, and cephalopods. The trilobites are more especially characteristic; they include some distinctively Cambrian genera (*Olenus*, *Agnostus*, *Dikelocephalus*, &c.), but they are marked by the appearance of new forms (*Angelina*, *Asaphellus*, *Cheirurus*, *Cyclognathus*, *Euloma*, *Nescuretus*, *Niobe*, *Parabolinella*, *Shumardia*, *Symphysurus*), a few of which attain a great development in the overlying Silurian system. The phyllocarids are represented by *Ceratiocaris* and *Lingulocaris*. The same genera, and in some cases species, of brachiopods appear which occur in the Lingula flags, *Orthis lenticularis* and *Lingulella Davisii* being common forms. Hicks described 12 species of lamellibranchs from the Tremadoc rocks of Ramsey Island and St. David's, belonging to the genera *Ctenodonta*, *Palæarca*, *Glyptarca*, *Davidia*, *Modiolopsis*. The cephalopods are represented by *Orthoceras sericeum* and *Cyrtoceras præcox*; the pteropods by *Hyolithes Davidii*, *H. operculatus*, and *Conularia Homfrayi*; the echinoderms by a beautiful star-fish (*Palæasterina ramseyensis*) and by a crinoid (*Dendrocrinus? cambrensis*).[2] Careful analysis of the fossils suggests a separation of the Tremadoc sub-group into two divisions. The most characteristic forms of the lower division are *Niobe Homfrayi*, *N. menapiensis*, *Psilocephalus* (*? Symphysurus*) *innotatus*, *Angelina Sedgwickii*, *Asaphellus affinis*, and more particularly *Dictyograptus flabelliformis* (*Dictyonema sociale*), which is a characteristic fossil of the uppermost Cambrian rocks in Scandinavia and Russia. The upper division contains *Asaphellus Homfrayi*, *Conocoryphe* (*Cyclognathus?*) *depressa*, and other fossils having a general Lower Silurian facies.

The peculiar fauna of this group has been shown by Professor Brögger to have a wide geographical extension. He designates it the *Euloma-Niobe* fauna, which is recognisable in the Christiania region, Bavaria, Southern France, Bohemia, and Sardinia, and can be traced in Canada and Newfoundland. He enumerates among its characteristic genera and sub-genera of trilobites the following forms: *Shumardia*, *Orometopus*, *Ceratopyge*, *Cyclognathus*, *Parabolinella* and *Angelina*, *Bavarilla*, *Nescuretus*, *Euloma*, *Harpides*, *Anacheirurus*, *Lichapyge*, *Apatocephalus*, *Dikelocephalina*, *Dikelocephalus*, *Asaphelina*, &c. He regards it as a distinct subdivision between the *Dictyograptus*-slates below and the Silurian strata with *Tetragraptus*, *Phyllograptus*, &c. (p. 969).[3]

It was the opinion of the late Sir A. C. Ramsay that though no visible unconformability can be seen at the top of the Tremadoc group, nevertheless there is evidence on a large scale of the transgressive superposition of the Arenig rocks upon the Tremadoc Slates and Lingula flags below them.[4] The transitional character of the *Euloma-Niobe* fauna, however, would appear to indicate that in the region of North Wales no serious interruption of the continuity of the sedimentation took place, nor any marked interference with the progress of biological evolution. The vagueness of the boundary line between the Cambrian and Silurian systems is only a proof of the artificiality of our stratigraphical subdivisions, and the variety of opinion as to where the line should be drawn points to the essential unity of type in the Cambrian and Silurian faunas.[5]

[1] Callaway, *Q. J. G. S.* xxxiii. (1877), p. 652. Lapworth, *op. cit.* (1888), p. 485; (1891), p. 533.

[2] Hicks, *Q. J. G. S.* xxix. p. 39.

[3] *Nyt. Mag.* xxxvi. (1898), p. 239.

[4] *Mem. Geol. Surv.* iii.; 'Geology of North Wales,' p. 250.

[5] On the subject of this boundary line, consult besides Brögger's recent paper above cited,

In various parts of England representatives of the Cambrian system have been discovered. One of the most important of these is in the range of the Malvern Hills, where the subjoined groups, comprising some 3000 feet of strata, are recognisable in descending order :[1]—

4. Bronsil grey shales, 1300 feet, including about 300 feet of diabases and basalts : *Dictyonema sociale, Tomaculum problematicum, Lingulella Nicholsoni, Linnarssonia Belti, Obolella* (?) *Salteri, Hyolithes assulatus, Agnostus dux, Olenus (Parabolinella) triarthrus, Niobe Homfrayi*, &c. This subdivision is believed to correspond, on the whole, with the Lower Tremadoc beds of North Wales.
3. White-leaved-Oak black shales, which, including two bands of olivine-basalt (300 feet), have a thickness of about 800 feet ; separable into two zones ; (*a*) that of *Polyphyma*, containing *Polyphyma Lapworthi* (a fossil probably allied to *Beyrichia Angelini*), *Protospongia fenestrata, Acrotreta* (?) *Sabrinæ, Kutorgina cingulata, Lingulella Nicholsoni*, and (*b*) that of *Sphærophthalmus*, containing *Sphærophthalmus alatus* (= *Olenus humilis*, Phill.), *Ctenopyge bisulcata, Peltura scarabæoides, Agnostus trisectus, Lingulella pygmæa, Murchisonia* !, *Glyptarca primæva*, ostracods, sponge-spicules, foraminifera, &c. This subdivision includes strata that may be correlated with the upper part of the Lingula Flags (Upper Dolgelly Beds).
2. Hollybush Sandstones, perhaps 1000 feet thick : *Kutorgina cingulata, Phillipsii, Linnarsonia sagittalis, Orthotheca* (*Hyolithes*) *fistula, Hyolithes primævus* (and several other species), *Scolecoderma antiquissima, Medusopsis* (?), foraminifera as glauconitic casts.
1. Malvern quartzite and conglomerate, perhaps 200 or 300 feet : Fossils rare, include *Kutorgina Phillipsii, Obolella Groomii, Hyolithes primævus, Orthotheca fistula*, foraminiferal glauconitic casts.

The various subdivisions of the Cambrian system were probably deposited over the Midland region of England, but they have been for the most part buried under younger formations, and are now only visible at a few places where they have been ridged up and denuded. In the Wrekin and Caradoc district the Cambrian strata, about 2000 feet thick, have at their base the Wrekin Quartzite, 100 to 200 feet thick, which has yielded a few worm-burrows. It is succeeded by the Comley or Hollybush Sandstone, which in places is shaley and calcareous, and has furnished in the lower parts *Olenellus Callavei, Agraulos, Stenotheca*, and *Kutorgina cingulata* ; in the upper parts *Paradoxides Groomii*. Above those sandstones lie the Shineton Shales, containing a fauna like that of the Tremadoc Slates. At the base *Dictyonema sociale* is found, in the middle portion forms of *Bryograptus*, and in the highest beds many genera and species of the Lower Silurian family of the Asaphidæ, in association with species of *Olenus* and other Cambrian forms.[2]

In the Nuneaton district of Warwickshire another inlier of ancient strata was first recognised as Cambrian by Professor Lapworth. It has the Hartshill quartzites at the bottom, with their interstratified zones of shale, and near the top a thin band of reddish limestone containing species of *Hyolithes* and *Orthotheca, Coleoloides typicalis, Stenotheca rugosa, Kutorgina cingulata*, &c. These fossils suggest a Lower Cambrian horizon. Next come the Stockingford shales, divisible into three groups, the Purley shales at the bottom, with (?) *Conocoryphe coronata, Acrothele granulata, Lingula* sp., *Obolella sagittalis, Hyalostelia, Protospongia fenestrata*. In the middle lie the black Oldbury shales, with *Ctenopyge pecten, Sphærophthalmus alatus, Olenus, Agnostus pisiformis, Beyrichia Angelini*, &c. The uppermost or Merevale shales are marked by the occurrence of *Dictyonema sociale*, and are probably, like the Bronsil shales of Malvern, somewhere

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his 'Silurischen Etagen 2 und 3 im Kristiania Gebiet,' 1882, p. 156. Linnarsson, *Geol. Fören. Stockholm*, ii. (1874), p. 273. J. E. Marr, 'Classification of the Cambrian and Silurian Rocks,' 1883, p. 23 ; 'Principles of Stratigraphical Geology,' 1898, p. 152. J. C. Moberg, *Sverig. Geol. Undersökn.* C. No. 109 (1890).

[1] Professor T. Groom, *Q. J. G. S.* lviii. (1902), p. 89.

[2] Professor Lapworth, *Proc. Geol. Assoc.* 1898, p. 337.

about the horizon of the Lower Tremadoc or Upper Dolgelly slates of North Wales.[1] In the heart of the Lickey Hills a quartzite like that of Nuneaton is referred to the Cambrian system. It has only furnished some worm-burrows.

In the south-east of Ireland masses of purplish, red and green shales, slates, grits, quartzites and schists occupy a considerable area, and attain a depth of apparently several thousand feet without revealing their base, though in Wexford they may possibly rest on pre-Cambrian rocks. They have yielded *Oldhamia*, also numerous burrows and trails of annelides (*Histioderma hibernicum*, *Arenicolites didymus*, *A. sparsus*, *Haughtonia pœcila*). In the absence of fossil evidence it is impossible to bring these strata into correlation with those of Wales. Some portions of them have been considerably metamorphosed. On the Howth coast they appear as slates, schists and quartzites.

Continental Europe.—According to the classification adopted by M. Barrande, the faunas of the older Palæozoic rocks of Europe suggest an early division of the area of this continent into two regions or provinces,—a northern province, embracing the British Islands, and extending through North Germany into Scandinavia and Russia, and a central-European province, including Bohemia, France, Spain, Portugal and Sardinia.

Passing from the British type of the Cambrian deposits, we encounter nowhere in the northern part of the continent so vast a depth of stratified deposits; on the contrary, one of the most singular contrasts in Palæozoic geology is that presented by the development of these formations in Wales, and in the north of Europe. The enormous masses of sediment, thousands of feet thick, and with such uniformity of lithological character, which record the oldest Palæozoic ages in Wales, are represented in the basin of the Baltic by only a few hundred feet of sediments, which show strongly separated lithological subdivisions. Again, while the English and Welsh rocks have been much disturbed, those in the eastern part of the Baltic basin remain over wide tracts hardly altered from their original condition of level sheets of sand and clay.

In Scandinavia the Cambrian system lies with a strong unconformability on pre-Cambrian rocks.[2] The so-called "Primordial zone" of this region appears to be everywhere characterised by uniformity of lithological composition as well as of fossil contents, consisting mainly of black shales with concretions or thin seams of fetid limestone. The following grouping of the Cambrian system has been made, the whole thickness of strata being about 400 feet (120 metres).

3*a*. Limestone and shale with the *Euloma-Niobe* fauna (see pp. 922, 969).

2. Olenus group. About 200 feet of bituminous fissile alum-shales, with nodules and layers of fetid limestone. The following zones in descending order were

[1] Lapworth, *op. cit.* pp. 338-350.

[2] For Scandinavian Cambrian rocks see Angelin, 'Palæontologia Suecica,' 1851-54. Kjerulf, 'Norges Geologi,' 1879 (or 'Geol. Süd. und Mittl. Norwegen,' 1880). Dahll, *Vidensk. Selsk. Förhandl.* 1867. Nathorst, *Kongl. Vet. Akad. Förhandl.* 1869, p. 64, and 'Sveriges Geologi.' pp. 116-154. (The appendix to this volume contains a detailed catalogue of the literature of Swedish Geology.) Torell, *Acta Univers. Lund.* 1870, p. 14; *Kongl. Vet. Akad. Förhandl.* 1871, No. 6. Linnarsson, *Svensk. Vet. Akad. Handl.* 1876, iii. No. 12; 'Om Agnostus-Arterna,' &c., *Sverig. Geol. Undersökn*, ser. C. No. 42, 1880; 'De undre Paradoxides lageren vid Andrarum,' *op. cit.* ser. C. No. 54, 1883; *Geol. Mag.* 1869, p. 393; 1876, p. 145. Tullberg, 'Skånes Graptoliter,' *Sverig. Geol. Undersökn.* ser. C. Nos. 50, 55 (1882-83); *Z. Deutsch. Geol. Ges.* xxxv. (1883), p. 223. W. C. Brögger, *Nyt. Mag.* 1876; *Geol. Fören. Stockholm*, 1875-76, 1886, p. 18; 'Die Silurischen Etagen 2 and 3 im Kristiania Gebiet,' 1882. Lundgren in text to Angelin's Geol. Map of Sweden, *N. Jahrb.* 1878. S. L. Törnquist, *Ofvers. Akad. Förh.* Stockholm, 1875; *Geol. Fören. Stockholm*, xi. (1889), p. 299. J. C. Moberg, *op. cit.* xii. (1890), p. 447; xxii. p. 523; xxiv. (1902), p. 44. Moberg and H. Möller, *op. cit.* xx. pp. 197-290. Lapworth, *Geol. Mag.* 1881, p. 260; 1888, p. 484. Marr, *Q. J. G. S.* xxxviii. (1882), p. 313; 'Classification of the Cambrian and Silurian Rocks,' 1883, pp. 72-100.

noted by S. A. Tullberg—(*k*) zone with *Acerocare ecorne*, (*i*) *Dictyograptus flabelliforme*, (*h*) *Cyclognathus micropygus*, (*g*) *Peltura scarabæoides*, (*f*) *Eurycare camuricorne*, (*e*) *Parabolina spinulosa*, (*d*) *Ceratopyge* sp., (*c*) *Olenus*, a special zone of this genus, of which it has many species, (*b*) *Leperditia* sp., (*a*) *Agnostus pisiformis*. J. C. Moberg recognises five zones in this group, which in descending order are: (5) *Acerocare* and *Peltura*, (4) *Sphærophthalmus* and *Eurycare*, (3) *Parabolina spinulosa*, (2) *Olenus truncatus*, (1) *Agnostus pisiformis* (*forma typica*).[1] Professor Brögger has abbreviated this subdivision by making two chief zones, a higher (2 *d*) with *Peltura*, *Cyclognathus*, &c., and a lower (2 *a-c*) with *Olenus* (in the strict sense) *Parabolina*, *Eurycare*, &c. He maintains, in the paper already cited, that the *Dictyograptus* (*Dictyonema*) beds should be placed in the Lower Silurian, and accordingly he draws the line for the top of the Cambrian series at the bottom of these beds (p. 969).

1. *c*, *d*. Paradoxides group. About 160 feet of sandy shales, alum shales, with three bands of limestone, the lowest (1½ feet), known as the "Fragmentenkalk," the middle as the "Exsulanskalk," and the highest (2 to 3 feet) the "Andrarumskalk." Tullberg divides the group into the following zones in descending order, (*m*) *Agnostus lævigatus*, (*l*) *Paradoxides Forchhammeri*. (This is the horizon of the Andrarum limestone, which contains an abundant fauna, including many species of *Agnostus* and other trilobites.) (*k*) *Agnostus Lundgreni*, (*i*) *Paradoxides Davidis*, (*h*) *Conocoryphe æqualis*, (*g*) *Agnostus* [illegible], (*f*) *Agnostus intermedius*, (*e*) *Microdiscus scanicus*, (*d*) *Conocoryphe exsulans*, (*c*) *Agnostus atavus*, (*b*) "Fragmentenkalk" with *Paradoxides ölandicus*, (*a*) Black alum-shale with *Lingulella*, *Acrotreta*, *Obolella*, &c. Professor Brögger recognises two chief bands, the higher marked by *Paradoxides Forchhammeri*, the lower by *P. ölandicus*, *P. Tessini*, *P. Davidis*, &c.

1. *b*. Olenellus group, consisting of two thin bands of strata (*b*) Phosphate limestone and sandy shale with *Lingulella*, *Acrothele*, &c., (*a*) Sandy shales passing into sandstone (greywacke-shale) with *Olenellus Kjerulfi*, *Ellipsocephalus Nordenskioldi*, *Arionellus primævus*, *Hyolithes*, &c.[2]

Though the Scandinavian Cambrian series is so much thinner than that of Wales, it contains the three distinctive life-platforms recognisable in Britain, and appears thus to be a full palæontological and homotaxial equivalent of the much fuller development of sedimentary material in Britain. But, as has already been pointed out (p. 900), the older Palæozoic formations of Norway and Sweden display remarkable lithological differences on the east and west sides of the axis of the peninsula, suggestive of a former land-barrier, on the two sides of which the character and thickness of the sediments were strongly contrasted. On the eastern side the Cambrian and Silurian formations present the normal fossiliferous aspect above described, but on the western side they consist of vast piles of crystalline schists, which might be taken for pre-Cambrian formations if their true age were not indicated by the occasional occurrence of organic remains in some parts of them. The lower group of these metamorphosed rocks, known as the Röros schists, consists of markedly crystalline soft mica-schists and hornblende-mica-schists. No fossils have been found in it, but on stratigraphical grounds it is regarded by Törnebohm as probably of Cambrian age.[3] The overlying schists and limestones are believed to be Silurian.

The most extensive tract of fossiliferous, older Palæozoic strata in Scandinavia extends among the Archæan rocks and crystalline schists as a broad but interrupted belt from Jemtland through Norrland and Vesterbotten into Lapland, a distance of more than 400 English miles. In this area both Cambrian and Silurian formations are well developed, and present the same recognisable zones as in Southern Scandinavia, though

[1] *Geol. Fören. Stockholm*, xxii. (1900), p. 533.

[2] S. A. Tullberg, *Afhand. Sverig. Geol. Undersökn.* ser. C. No. 50 (1882). W. C. Brögger, *Geol. För. Stockholm*, No. 101, vol. viii. (1886), p. 196; *Norges. Geol. Undersøg.* No. 11 (1893). K. A. Grönwall, *Geol. För. Stockholm*, xxiv. 1902, pp. 309-345. The figures in this table are continued upward into the base of the Silurian system (p. 969).

[3] *Sverig. Geol. Unders.* ser. Ba. No. 6 (1901), p. 43.

with many local differences, both in the nature of the sediments and the character of the fauna which they contain. In Jemtland a zone of sandstone lying on the Archæan gneiss contains the *Olenellus*-zone, and is followed by the alum-slate, with nodules of fetid limestone containing the zones of *Paradoxides œlandicus*, *P. Tessini*, and *P. Forchhammeri* and a considerable assemblage of other trilobites. Higher bands of alum-slate with similar calcareous nodules form the *Olenus* group, composed of the zones of *Agnostus pisiformis*, *Olenus gibbosus*, *Parabolina spinulosa*, *Eurycare latum* and *Peltura scarabæoides*.[1] The same zones are prolonged northward along the border country between Sweden and Norway. In the district of Täsjön, in the west of Vesterbotten, among the tracts of quartzite and sparagmite the following upward succession of Cambrian strata has been observed: 1, Grey pyritous quartzite; 2, Fossiliferous limestone and quartzose band, containing small concretions of phosphorite (9 cm.), and covered with a thin parting of alum-slate and dark grey limestone with *Paradoxides;* 3, Black limestone (18 cm.) containing *Liostracus Linnarssoni*, *Acrothele*, sp. and indicating the zone of *Paradoxides Tessini*. Above a thin phosphoritic layer lies (4) a greyish black fossiliferous limestone (3 cm.) with a *Paradoxides*, possibly *P. Forchhammeri* and *Solenopleura* (?); 5, Alum-slate. From the same band of strata there have likewise been obtained *Agnostus gibbus*, *A. intermedius*, *A. parvifrons*, marking the *Paradoxides Tessini* zone, and from other localities in the same district, *Paradoxides ölandicus*, *P. Forchhammeri*, *Peltura*, *Sphærophthalmus*, *Solenopleura brachymetopa*.[2]

The Cambrian type of Southern Sweden undergoes considerable modification as it passes eastwards, into the Baltic provinces of Russia. The black shales so characteristic in Scandinavia thin away, and the distinctive Paradoxidian and Olenidian divisions disappear. A group of strata, traceable from the S.E. of Lake Ladoga for a distance of about 330 miles to near Baltischport on the Gulf of Finland, with a visible thickness of not more than 100 feet (but pierced to a depth of 600 feet more in artesian wells) consists of three subdivisions: (*a*) Blue clay composed of a lower set of iron-sandstones (300 feet), resting on granite and an upper blue clay (300 feet), formerly noted only for some obscure fossils (*Platysolenites*, Pander, probably fragments of cystideans), but now known to include the *Olenellus*-zone; (*b*) Ungulite grit (50 to 60 feet), containing *Obolus Apollinis* (*Ungula*, Eichw.) *Schmidtia celata*, &c.; (*c*) *Dictyonema*-shales (about 20 feet), with *Dictyograptus* (*Dictyonema*) *flabelliformis*.[3] The researches of Schmidt have clearly shown the relations between these soft and seemingly not very old deposits and the Cambrian system of the rest of Europe. The lower sandstone, blue clay and a fucoidal sandstone lying immediately above the latter form an unequivocally Lower Cambrian group, for they have yielded *Olenellus Mickwitzi*, *Scenella discinoides*, *Mickwitzia monilifera*, *Obolella*, *Discina*, *Volborthella* (doubtfully referred to the Orthoceratites), *Platysolenites* and *Medusites*. Professor Schmidt points out that a complete break occurs between the top of the fucoid sandstone and the base of the Ungulite sandstone, and that this hiatus represents the Paradoxidian and Olenidian groups, while the Dictyonema-shales form the characteristic uppermost zone of the system.[4] The Cambrian sea is known to have stretched into Siberia, for Schmidt has described *Agnostus* from the Olenek in lat. 71°. The genera *Liostracus* and *Anomocare* also occur in that region, while in the valley of the Lena limestones with *Microdiscus* represent the *Olenellus*-zone, which extends to near Jakutsk. The same zone, as a limestone containing *Archæocyathus*, appears in the island of Vaigatch.

[1] C. Wyman, *Bull. Geol. Inst. Upsala*, vol. i. No. 2, 1893, and references there given.

[2] H. Lundbohm, *Afhandl. Sverig. Geol. Undersökn.* ser. C. No. 177, 1899, p. 33.

[3] F. Schmidt, *Q. J. G. S.* xxxviii. (1882), p. 516.

[4] *Mém. Acad. Imp. Sci. St. Pétersb.* xxxvi. (1889), No. 2; *Bull. Acad. St. Pétersb.* xxx. p. 501; "Excursion durch Estland," "Guide des Excursions," No. 12, *Congrès. Géol. Internat.* St. Petersb. 1897. E. von Toll, *Mém. Acad. St. Pétersb.* viii. (1899), No. 10.

In Central Europe, Cambrian rocks rise from under later accumulations in Belgium and the north of France, Spain, Bohemia, and the Thuringer Wald.[1] The most important in France and Belgium is that of the Ardennes,[2] where the principal rocks are grit, sandstone, slates, and schistose quartzites or quartz-schists (quartzo-phyllades of Dumont), with bands of whet-slate, quartz-porphyry, diabase, diorite, and porphyroid. According to Dumont these rocks, comprehended in his 'Terrain Ardennais,' can be grouped into three great subdivisions—1st and lowest the "Système Devillien," pale and greenish quartzites with shales or phyllades, containing *Oldhamia radiata*, and annelid tracks (*Nereites*): 2nd, the "Système Revinien," phyllades and black pyritous quartzites from which *Dictyograptus flabelliformis* (*Dictyonema sociale*), and worm-burrows have been obtained; 3rd, the "Système Salmien," consisting mainly of quartzose and schistose strata or quartzo-phyllades, and yielding *Dictyograptus flabelliformis*, *Chondrites antiquus* and *Lingula*. The Devillian and Revinian divisions are united by Gosselet into one series composed of (*a*) Violet slates of Fumay; (*b*) Black pyritous shales of Revin; (*c*) magnetite slates of Deville; (*d*) Black pyritous shales of Bogny. These rocks have been greatly disturbed. They are covered unconformably by Devonian and later formations.

In the north-west of France, extending through the old provinces of Brittany, the west of Normandy and the north of Poitou, a great isolated mass of ancient rocks rises out of the plains of Secondary formations, and the pre-Cambrian rocks already referred to are there succeeded, with a more or less distinct unconformability, by a thick series of sedimentary groups which are now considered to be of Cambrian age. In western Brittany the pre-Cambrian green silky schists known as the "Phyllades de Douarnenez," which are believed to be about 3000 metres thick, are followed, perhaps unconformably, by purple conglomerates, sometimes 530 metres thick, passing up into red shales which have a vertical depth of 2500 metres, and are surmounted by the Grès Armoricain or bottom of the Silurian system. In these strata *Scolithus* and *Tigillites* occur, but recognisable fossils are extremely rare, and no trace has yet been found here of the more typical Cambrian forms. In the basin of Rennes considerable bands of limestone, sometimes magnesian, together with quartzites, conglomerates, and greywackes occur in the Cambrian series. Great local variations appear in the lithology and thickness of the series; in Central Brittany it is marked by the intercalation of acid lavas and volcanic tuffs. In the region of the Sarthe, the basement conglomerates are followed by grey shales with thick bands of siliceous and magnesian limestone, above which lies a series of sandy rocks containing *Lingula crumena* and passing under the Grès Armoricain.[3] In Southern France, from the Cambrian rocks which flank the

[1] The student will find a useful compendium on the correlation of the Cambrian and Silurian rocks of Western Europe by S. Törnquist in *Geolog. Fören. Stockholm Förh.* xi. (1889), p. 299.

[2] Dumont, 'Mémoires sur les Terrains Ardennais et Rhénan,' 1847-48. Dewalque, 'Prodrome d'une Description Géol. de la Belgique,' 1868. Mourlon, 'Géologie de la Belgique,' 1880. Gosselet, 'Esquisse Géol. du Nord de la France,' &c., 1880, and his great Monograph, 'L'Ardenne' *Mem. Carte. Géol. detaill.* 4to, 1888. C. Malaise. *Bull. Acad. Roy. Belg.* 3rd ser. ii. (1881), No. 8; *op. cit.* v. (1883), No. 1 and No. 6; *Congr. Géol. Internat. Paris*, 1900, p. 561. The petrography of these rocks has recently been again discussed by Dr. J. de Windt, *Mem. Cour. Sav. Etrang. Acad. Roy. Belg.* lvi. (1898); and their stratigraphy by M. Lohest and H. Forir, *Ann. Soc. Geol. Belg.* xxv. *bis.* 1899-1900.

[3] The (pre-Cambrian) phyllades of Brittany and the (Cambrian) purple conglomerates and red shales which succeed them were exhaustively treated by Hébert, *B. S. G. F.* (3) xiv. p. 713. See also Tromelin et Lebesconte, *B. S. G. F.* iv. (1876), p. 5. 583; *Assoc. Franc.* 1875. Tromelin, *Assoc. Franc.* (1879), p. 493. Lebesconte, *B. S. G. F.* (3) x. p. 55; xiv. (1886), p. 776; xvii. (1889), p. 621; xix. (1891), p. 15. Guillier, *op. cit.* (3) ix. p. 374. Barrois, *op. cit.* v. (1877), p. 266; *Carte. Géol. France.* Redon Sheet: *Ann.*

isolated pre-Cambrian axis of Upper Languedoc, the most satisfactory fossil evidence has been obtained, showing the existence there of both the Paradoxidian (*Paradoxides, Conocoryphe*) and Olenidian divisions of the Cambrian system.[1] Among the French Pyrenees, narrow strips and patches of strata have been detected which, lying below fossiliferous Lower Silurian rocks, are believed to be Cambrian.[2]

In various parts of Spain indications of the presence of Cambrian rocks are furnished by Primordial fossils. In the province of Seville the highest beds have yielded *Archæocyathus*, and in the province of Ciudad-Reale, Primordial tribolites (*Ellipsocephalus*). But it is in the Asturias that the most abundantly fossiliferous rocks of this age occur. They are grouped by Barrois into (*a*) Slates of Rivadeo, blue phyllades and green slates and quartzites, in all about 3000 metres, and (*b*) *Paradoxides* beds of La Vega (50 to 100 metres) composed of limestones, slates, iron-ores, and thick beds of green quartzite. In the upper part of (*b*) a rich Primordial fauna occurs, comprising a cystidean (*Trochocystites bohemicus*) and trilobites of the genera *Paradoxides*, 2 species, *Conocoryphe* (*Conocephalites*), 3 species, and *Arionellus*, 1 species.[3]

In the Portuguese part of the Iberian peninsula Cambrian strata have likewise been recognised by organic remains. In the Alto Alemtejo a dark grey shale in the line of contact between some limestones and quartzites, has yielded a number of fragmentary trilobites representing seven or eight different species belonging to the families of the Olenidæ and Conocephalidæ.[4]

In the Thuringer Wald certain phyllites, fucoidal slates, quartzites, &c., are referred to the Cambrian system. They have yielded some indistinct fossils (*Phycodes, Archæocyathus?*) and in their higher parts (Tremadoc) *Olenus, Euloma, Dikelocephalus, Niobe, Amphion, Ceratopyge*.[5] The Central European type of the Cambrian system is best developed in Bohemia, where the classic researches of Barrande have given to it an extraordinary interest. At the base of the Bohemian geological formations lie the slates which Barrande placed as his Étage A (Przibram schists), and which are no doubt pre-Cambrian (p. 901). They are overlain by vast masses of conglomerates, quartzites, slates, and igneous rocks (Étage B), which have been more or less metamorphosed, and are singularly barren of organic remains, though some of them have yielded traces of annelids (*Arenicolites*). They pass up into certain grey and green fissile shales, in which the earliest well-marked fossils occur. The organic contents of this Étage C or Primordial zone (300 to 400 metres thick) form what Barrande termed his Primordial fauna, which yielded him 40 or more species, of which 27 were trilobites, belonging to the characteristic Cambrian genera—*Paradoxides* (12), *Agnostus* (5), *Conocoryphe* (4), *Ellipsocephalus* (2), *Hydrocephalus* (2), *Arionellus* (1), *Sao* (1). Not one of these genera, save *Agnostus* (of which four species appear in the second fauna), were found by Barrande higher than his Primordial zone. Among other organisms in this Primordial fauna, the

Soc. Géol. Nord. xv. p. 238; xxii. (1894); *Bull. Carte. Géol. France*, No. 7 (1890), p. 74. Oehlert, *op. cit.* Nos. 38 and 44.

[1] J. Bergeron, *B. S. G. F.* xvi. (1888), p. 282; 'Etude géologique du Massif ancien au sud du Plateau central,' 1889. J. Miguel, 'Note sur la Géologie des Terrains Primaires du Départment de l'Hérault,' 1894, calls attention to a mass of strata lying between the highest Paradoxidian beds and the base of the Arenig formation, into which it graduates. It attains a thickness of 1000 metres, and is compared by him with the Tremadoc group. See also J. F. Pompeckj, *Neues Jahrb.* 1902, i. p. 1.

[2] J. Caralp, 'Etudes géol. sur les hauts massifs des Pyrénées centrales,' 1888, p. 452. E. Jacquot, *B. S. G. F.* 1890, p. 640.

[3] Barrande, *Bull. Soc. Géol. France* (2) xvi, p. 543. Macpherson, *Neues. Jahrb.* 1879, p. 930. Barrois, *Mém. Soc. Géol. Nord.* ii. (1882), p. 168.

[4] J. F. Nery Delgado, *Com. Direc. Trab. Geol. Portugal*, iii. (1895), p. 97.

[5] H. Loretz, *Jahrb. Preuss. Geol. Landesanst*, 1881, p. 175. Marr, *Geol. Mag.* 1889, p. 411.

brachiopods are represented by species of *Orthis* and *Orbicula*, the pteropods by *Hyolithes*, and the echinoderms by cystideans. It is worthy of note that the fossil contents of the zone on the opposite sides of the little Bohemian basin were found by the same great pioneer to be not quite the same, only eight species of trilobites being common to both belts, while no fewer than 27 species were detected by him only on one or other side. The Olenidian trilobites which characterise the upper Cambrian group were not observed by him in Bohemia.[1] Later researches have modified some of the stratigraphical details of his work, the geological structure of the country having been found to be much less simple than he supposed. But the fundamental grouping which he established remains much as he left it. A portion of his Stage B, the whole of his Primordial zone (Stage C), and a part of the base of his Stage D (Lower Silurian), was grouped together by Dr. Katzer in four members as the Cambrian development in Central Bohemia thus: (*a*) Basement conglomerates, (*b*) Paradoxides shales, (*c*) Quartz-greywacke group, (*d*) Diabase and red iron-ore group.[2] More recently Pompeckj has made in greater detail a study of these strata, in which he recognises two main groups: a lower, consisting of sandstones and greywackes passing down into conglomerates, which lie unconformably on the phyllites below; the greywackes, containing species of *Orthis*, *Stenotheca*, *Conocephalites*, *Ptychoparia* (*Conocephalites*), *Solenopleura*, *Ellipsocephalus*, *Sao*; and an upper group of conglomerates and shales, with the *Paradoxides* fauna as first shown by Barrande. The first of these two groups is paralleled with the *Olenellus*-zone, though no specimens of *Olenellus* have yet been found in it; the second group is a good development of the *Paradoxides* series of strata.[3]

In Russian Poland the older Palæozoic formations have at their base some quartzites, conglomerates, and shales, which around Sandomir on the left bank of the Vistula contain abundant fragments of *Paradoxides* (probably *P. Tessini* or *P. Bohemicus*), *Agnostus* (*A. fallax* and *A. gibbus*) with *Liostracus Linnarssoni* indicating a Middle Cambrian horizon.[4]

In Sardinia a characteristic assemblage of Cambrian fossils has been described, comprising three species of *Paradoxides*, six of *Conocephalites*, five of *Anomocare*, five of *Olenus*, as well as other forms.[5]

North America.—During the last two decades a large amount of attention has been paid by the geologists of the United States and of Canada to the study of the stratigraphy and fossil contents of the Cambrian rocks of North America, and the result of their labours has been to show that, whether as regards extent and thickness of strata, or variety and abundance of organic remains, these rocks surpass in importance the corresponding European series. The European types of sedimentation are there replaced by a varied assemblage of materials, among which limestone plays a large part; and this change, as might be expected, is accompanied by a remarkable contrast in the general facies of the fossils. Nevertheless, the leading type-genera of Europe have been found in their usual sequence, so that it has been possible to subdivide the American Cambrian system into three groups, which can be broadly correlated with the threefold arrangement adopted in Europe.[6]

[1] See his colossal work, 'Système Silurien de la Bohème,' published in successive parts and volumes from 1852 up till after his death in 1883; also Marr, *Q. J. G. S.* xxxvi. (1880).

[2] F. Katzer, 'Das ältere Palæozoicum in Mittleböhmen,' Prague, 1888; 'Geologie von Böhmen,' Prague, 1892, p. 804.

[3] J. F. Pompeckj, *Jahrb. K. K. Geol. Reichsanst*, xlv. pp. 495-614.

[4] G. Gürich, *Verhandl. Russ. K. Mineral. Gesell.* St. Petersburg, xxxix. (1896), p. 16.

[5] C. Meneghini, *Mem. Cart. Geol. Ital.* iii. Part 2 (1888). Bornemann, 'Die Versteinerungen des cambrischen Schichtensystems des Insel Sardinien.' Halle, 1886. J. F. Pompeckj, *Z. D. G. G.* liii. (1901) p. 1.

[6] Among writers on the Cambrian palæontology of North America a high place must be assigned to James Hall, E. Billings, C. D. Walcott, and G. F. Matthew. Mr. Walcott has

From the straits of Belle Isle the Cambrian formations of North America run through Newfoundland and Nova Scotia into New Brunswick. From the eastern coast of Gaspé they stretch along the right bank of the St. Lawrence to Lake Ontario. In several approximately parallel bands they range through the north-eastern states of the Union, spreading out more widely in the north of New York State, and in Vermont and Eastern Massachusetts. They rise along the Appalachian ridge, striking through Pennsylvania, Maryland, Virginia, Tennessee, and Georgia, down into Alabama, to a distance in the eastern part of the continent of about 2000 miles. In the heart of the continent, again, they rise to the surface, and flanking the vast pre-Cambrian region of the north, extend over a wide area between Lake Superior and the valley of the Mississippi in the States of Michigan, Wisconsin, and Minnesota. An isolated tract of them is found in Missouri, and another in Texas. The great terrestrial movements which ridged up the Rocky Mountains and their offshoots have brought the Cambrian rocks once more to the surface from under the vast pile of younger formations beneath which, during a large part of geological time, they lay buried. Hence along the axes of these elevations of the terrestrial crust they can be traced in many lines of outcrop from Arizona northwards through Utah, Colorado, Nevada, Wyoming, Dakota, and Montana, whence they strike far northward into the Dominion of Canada.

In thickness and lithological character the Cambrian rocks of North America exhibit considerable variation as they are traced across the continent, and these changes afford interesting evidence of the geographical conditions and geological revolutions of the region in the early ages of Palæozoic time. In Newfoundland, where the three groups of the system have been recognised, the total depth of strata measured by A. Murray was about 6000 feet, of which the lower division forms only about 200 feet. In Western Vermont and Eastern New York the total depth of the system seems to be about 7000 feet; and of this great mass of sedimentary material the lower division may occupy perhaps as much as 5000 feet.[1] Over the central parts of the continent west of the line of the Mississippi the thickness diminishes to 1000 feet or less; but again to the west of the Rocky Mountains it increases to 7000 feet or more in Nevada, while in British Columbia it rises to 10,000 feet.

In the north-eastern regions the sediments were chiefly muddy, and are now represented by thick masses of shale with a little sandstone and limestone. The limestones increase in number and thickness southwards in Vermont, where a considerable

devoted himself to the subject with untiring enthusiasm and much skill. His most important memoirs will be found in the Bulletins of the U.S. Geological Survey, Nos. 10 (1884), 30 (1886), 81 (1891), 134 (1896), in the 10th, 12th, and 14th Annual Reports, in Monographs viii. xx. xxxii. Part ii. p. 440, and notices in *Amer. Journ. Sci.* July, December 1892, January, April 1894, February 1895; *Proc. Washington Acad. Sci.* i. (1900), p. 301; *Proc. U.S. Nat. Museum*, xxi. (1898), p. 385. Of great importance also are the memoirs on the Cambrian Rocks and fossils of Canada, by Mr. Matthew, published in the *Trans. Roy. Soc. Canada*, from the first volume (1882) onwards, also in *Bull. Nat. Hist. Soc. New Brunswick*, No. 10 (1892); *Trans. New York Acad. Sci.* xiv. (1895), pp. 101-153; xv. (1896). The stratigraphical relations of the Cambrian formations have been discussed by many writers, among whom are R. D. Irving, *7th Ann. Rep. U.S. G. S.* (1888). N. S. Shaler, *Bull. Mus. Comp. Zool. Harvard*, xvi. No. 2 (1888). Emerson, *B. U.S. G. S.* No. 159; *Monogr. U.S. G. S.* No. xxix. (1898). A. C. Peale, *B. U.S. G. S.* No. 110. N. H. Winchell, *Amer. Geol.* xv. (1895), pp. 153, 229, 295; xvi. p. 269. C. R. Keyes, *Journ. Geol.* iii. p. 519. D. B. Dowling, *op. cit.* p. 988. J. B. Woodworth and A. F. Foerste, *Monog. U.S. G. S.* No. xxxiii. (1899).

[1] Walcott has found Olenellus about 2000 feet below the summit of the series, but he hesitates to assume that it can really range through such an enormous thickness of strata, *10th Ann. Rep. U. S. G. S.* p. 583. See his later section in *12th Ann. Rep.* (1892), Plate xlii.

mass of calcareous material lies in the lower group below several thousand feet of shale. Still further south the lower group consists largely of sandstones, which are followed by sandy, dolomitic, and purely calcareous limestones. In Nevada, where a thickness of 7700 feet has been assigned to the Cambrian system, the limestones are 4250 feet in aggregate thickness.[1]

It will be seen, therefore, that the nearest European parallel to the combination of thick arenaceous with thick calcareous accumulations, which distinguishes the Cambrian system of North America, is to be found in the north-west of Scotland. In this connection it is interesting to note that the general facies of the Scottish Cambrian fossils, so distinct from that of the rocks of Wales and the rest of Europe, and so much more akin to that of the United States and Canada, is accompanied by a markedly North American type of sedimentary material.

The following table gives the classification of the Cambrian system of North America:[2]—

3. Upper or Potsdam (Olenus and Dikelocephalus fauna).	Sandstones of N. and E. sides of Adirondack Mountains of New York and adjacent parts of Canada. On the same horizon lie the limestones S. of Adirondacks and Dutchess County, New York; and the shales of Tennessee, Georgia, and Alabama. In the west come the sandstones of the Upper Mississippi Valley, S. Dakota, Wyoming, Montana, and Colorado, the sandstones and calcareous beds of N. Arizona, and the limestones and shales of Nevada. In the far north-east are the black shales at the top of the New Brunswick and Cape Breton Island sections, and the shales and sandstones of Conception Bay, Newfoundland (Belle Isle).
2. Middle or Acadian (Paradoxides fauna).	Shales and slates of Eastern Massachusetts (Braintree), New Brunswick (St. John), and Eastern Newfoundland (Avalon). With these typical rocks are correlated part of the limestones of Dutchess County, New York (Stissing) and the central parts of the Tennessee and Alabama sections (Coosa), with limestones in Central Nevada and British Columbia (Mount Stephen). In the Yellowstone Park the middle Cambrian strata have yielded an abundant fauna.
1. Lower or Georgian (Olenellus fauna).	The typical locality is in Western Vermont, where shales and limestones are developed. With these are paralleled the quartzite of W. slope of Green Mountains and Appalachian chain in Pennsylvania, Virginia, Tennessee, Georgia, and Alabama; the shales and interbedded limestones and slates of S. Vermont and New York southward to Alabama; the limestone, sandstone, and shale of Straits of Belle Isle (Labrador), N.W. coast of Newfoundland and peninsula of Avalon (Placentia); the basal series of Hanford Brook Section, Caton's Island, &c., New Brunswick; the shales and limestones of E. and S. Massachusetts (Attleborough); the lower portion of the Eureka and Highland ranges, Nevada (Prospect); a portion of the Wasatch Cambrian Section (Cottonwood) and the base of the Castle Mountain, British Columbia.

Reference has already been made to the views of Mr. W. G. Matthew in regard to the pre-Cambrian age of a sedimentary series which underlies what he considers to be the oldest Cambrian strata of New Brunswick, and which he has grouped as "Etchiminian," from the name of an old Indian tribe of the country. He has found in the upper half of this series numerous burrows and tracks of annelids, Hyolithidæ being also particularly abundant and varied. Trilobites are rare and generally absent, the most frequent crustacea being bivalve entomostraca and small phyllocarids. Brachiopods are abundant, including the genera *Obolus*, *Lingulella*, and other horny forms, the calcareous Protremata being rare and of small size. Some small and rare gasteropods have been met with, but the patelloid forms are larger and more frequent. A few small

[1] A. Hague. *Ann. Rep. U.S. G. S.* 1881-82. Walcott, *Monogr. U.S. G. S.* vol. viii. (1884).

[2] C. D. Walcott, *Bull. U.S. G. S.* No. 81 (1891), p. 360.

lamellibranchs (*Modiolopsis*) complete the fauna, which comprises about 20 genera.[1] The claim of this group of strata to be considered pre-Cambrian is disputed by Mr. Walcott. According to his observations the *Olenellus* fauna occurs in Newfoundland 420 feet below the *Paradoxides* fauna in the heart of the "Etchiminian" group, and in New Brunswick fragments of it are found 460 to 480 feet down in that group. Mr. Matthew is disposed to think that *Olenellus* is rather a later than an earlier form than *Paradoxides*, but the general experience in both the Old World and the New is against this view.[2]

Mr. Matthew has proposed a different classification and nomenclature of the Cambrian formations of New Brunswick from that given in the foregoing table. Above his "Etchiminian" series he makes three subdivisions of the Cambrian system. 1st, The lowest or Acadian stage (650 feet), with the zone of *Ellipsocephalus* (*Agraulos*) *articephalus*, followed successively by those of *Paradoxides etemenicus* and *P. abenacus*; 2nd, the middle or Johannian stage (1000 feet), with the zones of *Lingulella Starri* and *L. radula*; and 3rd, the Bretonian stage (700 feet), with the zones of *Parabolina spinulosa*, *Peltura scarabæoides*, *Dictyonema flabelliforme*, and *Tetragraptus quadribrachiatus*. From these strata a remarkably abundant and diversified fauna has been obtained, which, according to Mr. Matthew, exhibits a remarkably close resemblance to that of the Cambrian formations around the Baltic Sea, but has little in common with that of the same formations in the interior of America, though only a few hundred miles separate them. The St. John's fauna includes fifty species of trilobites (*Agnostus* 12, *Agraulos* or *Ellipsocephalus* 7, *Conocoryphe* 3, *Paradoxides* 8, and others), two genera of cephalopods, three of gasteropods, four of pteropods (*Hyolithes*, *Diplotheca*, *Cyrtotheca*, *Styliola*), nine of brachiopods (*Obolus* 3 species, *Obolella*, *Linnarssonia* 3, *Lingulella* 9, *Clitambonites* 3, *Orthis* 6), besides a few ostracods, phyllopods, sponges, and sea-weeds. A number of graptolites appear in the upper division (*Dictyonema*, *Clonograptus*, *Loganograptus*, *Tetragraptus*, *Didymograptus*), but nearly all in the highest strata, which really belong to the Lower Silurian series.[3]

South America.—In the northern part of the Argentine Republic a representative of the Upper Cambrian or Olenus group has been found by Lorentz and Hyeronimus. It includes species of the genera *Lingula*, *Obolus*, *Orthis*, *Hyolithes*, *Arionellus*, *Agnostus*, and *Olenus*.[4]

China.—Baron von Richthofen has brought to light a succession of undisturbed strata (his "Sinisian formation"), which in Leao-tong and Corea attain a thickness of many thousand feet. In the higher parts of this series he found a characteristic assemblage of Primordial trilobites: *Conocoryphe* (*Conocephalites*) (4 sp.), *Anomocare* (6), *Liostracus* (3), *Dorypyge* (*Olenoides?*), *Agnostus* (1), with the brachiopods *Lingulella* (2) and *Orthis* (1).[5]

[1] W. G. Matthew, *Amer. Geol.* xxii. (1898), p. 252; *Bull. Nat. Hist. Soc. New Brunswick*, No. x. (1892), p. 34; iv. (1899), p. 198; *Geol. Mag.* 1899, p. 373; 1900, p. 87; *Ann. New York Acad. Sci.* xii. No. 2, pp. 41, 56; xiv. (1895), p. 101 (where the "Protolenus fauna" is described); *Trans. Roy. Soc. Canada*, 2nd ser. v. (1899), sect. 4, p. 39; vii. p. 138; *Compt. rend. Congrès. Geol. Internat.* Paris, 1900, p. 313. A large series of effusive and dyke rocks has been described as associated with the "Etchiminian series" of New Brunswick, W. D. Mattthew, *Trans. New York Acad. Sci.* xiv. (1895), p. 187.

[2] C. D. Walcott, *Bull. Geol. Soc. Amer.* x. (1899), p. 199; xi. (1899), p. 3. *Proc. Washington Acad. Sci.* vol. i. (1900), p. 301; *Compt. rend. Congrès. Geol. Internat.* Paris, 1900, p. 299. Mr. Walcott's account of the fauna of the *Olenellus*-zone is given in the 10*th Ann. Rep. U.S. G. S.* 1890. His description of the middle Cambrian fauna of the Yellowstone Park is included in *Mon.* xxxii. *U.S. G. S.* Part ii. p. 440.

[3] *Bull. Nat. Hist. Soc. New Brunswick*, No. 10 (1892), Appendix, p. xi.

[4] E. Kayser, 'Beiträge zur Geol. u. Palaeont. d. Argentinischer Republik,' Part ii. (1876).

[5] Richthofen, 'China,' vol. iii. (1882). W. Dames compares this Chinese Cambrian fauna with that of the Andrarumskalk of Scandinavia: *op. cit.* p. 32 (*ante*, p. 925). Mr.

India.—In the Salt Range a series of stratified formations, about 3000 feet in thickness, presents a peculiar development of the oldest Palæozoic strata, which there consist of sandstones, marls, shales, beds and pseudomorphs of rock-salt and deposits of gypsum. About 2000 feet above the base of this series lies a group known as the Neobolus or Khussak beds, about 100 feet thick, composed of the following subdivisions in descending order:

Lower magnesian sandstone, containing *Pseudotheca Waageni, Ptychoparia Richteri*, and passing up into hard clay with *Lingulella Fuchsi*.

Black compact clay-slate: *Hoeferia Noetlingi, Lingulella Wanniecki, Hyolithes*, &c. (zone of *Hoeferia Noetlingi*).

Red sandy micaceous beds, full of *Neobolus Warthi*, with *N. Wynni, Discinolepis granulata, Schizopolis rugosa, Lakhmina linguloides, L. squama, Lingula kiurensis, L. Warthi, Fenestella*, sp.

Upper annelid sandstone; glauconitic cream-coloured sandstone with thin alternations of soft beds: *Orthis Warthi, Hyolithes Wynni*.

Blackish-red sandstone with abundant *Hyolithes Wynni*, fragments of a trilobite and tracks of annelids. 10 feet.

Lower annelid sandstone: hard cream-coloured glauconitic sandstones alternating with thin bands of soft black sandstone, remnants of *Obolella*, fragments of *Hyolithes* and annelid tracks. 50 feet.

The lowest group of the series, known as the "Salt Marl," which is some 1500 feet thick, has yielded no fossils. The trilobite here named *Hoeferia* is a new genus, closely akin to *Olenellus*, by which name it was originally noticed by Waagen and Noetling. It is believed that the Neobolus beds cannot be later than the Paradoxidian group.[1]

Australasia.—In South Australia the oldest known fauna of the continent has been found at various places, and is recognisably Lower Cambrian. It includes species of *Conocephalites, Olenellus, Microdiscus, Clitambonites, Orthis, Ambonychia, Stenotheca, Ophileta, Platyceras, Salterella, Hyolithes, Protopharetra, Hyalostelia*, and *Girvanella*.[2] In Tasmania a considerable thickness of strata is placed by Mr. R. M. Johnston in the Cambrian system. The lowest group consisting of fossiliferous quartzites, clay-slates, and breccias, has yielded species of *Scolithus, Conocephalites* (or *Loganellus*), *Bathyurus, Asaphus, Dikelocephalus, Leptæna, Orthis, Ophileta* and *Tentaculites*.[3]

Section ii. Silurian.

Murchison was the first to discover that the so-called "Transition rocks," or "Grauwacke" of early geological literature, were capable of subdivision into distinct formations characterised by a peculiar assemblage of organic remains. As he found them to be well developed in the region once inhabited by the British tribe of Silures, he gave them the name of Silurian.[4] From the base of the Old Red Sandstone, he was able to trace his Silurian types of fossils into successively lower zones of the old "Grauwacke." It was eventually found that similar fossils characterised the older sedimentary rocks all over the world, and that the general order

Walcott inclines to believe that the fossils rather point to a Middle Cambrian fauna (*Bull. U.S. G. S.* No. 81, 1891, p. 379).

[1] K. A. Redlich, "The Cambrian Fauna of the Eastern Salt Range." *Palæontologia Indica*, new ser. vol. i. (1899), p. 1, where full references to previous authorities are given.

[2] R. Tate, *Trans. Roy. Soc. South Austr.* ii. (1879), pp. xlviii. and 77; xv. (1892), p. 183.

[3] 'Geology of Tasmania,' 1888, pp. 16-38.

[4] *Phil. Mag.* (3), vii. (1835), p. 47.

of succession worked out by Murchison could everywhere be recognised. Hence the term Silurian came to be generally employed to designate the rocks containing the first great fauna of the Geological Record.

This fauna, first worked out in its stratigraphical relations by Murchison, was shown by him to have such a marked uniformity of general character as to justify him in regarding it as distinctive of a single great geological system. Applying the principle so successfully adopted by William Smith for the Secondary formations of England—"strata identified by their organic remains,"— he from the first began to discriminate the groups of sedimentary deposits by the fossils contained in them, and eventually classified them in a series of successive formations ranging from the base of the Old Red Sandstone down to the oldest stratified rocks then known along the Welsh borders. These formations he was led to group into two great divisions, each marked by certain biological peculiarities. The older half of his system he termed Lower Silurian, and the later half Upper Silurian. It was found that the stratigraphical sequence of organic types first established by him in England and Wales holds good all over the world. Barrande demonstrated how completely the original Silurian classification was borne out by the abundantly fossiliferous formations of Bohemia. He was fortunate, however, in finding in that country a much fuller record of the earliest organic types than had been met with in Britain, and he was led to recognise the existence of three successive phases in the progress of animal life during the protracted Silurian period. To the oldest of these phases he gave, as we have seen, the name of the first fauna or Primordial zone, the second fauna was contained in Murchison's Lower Silurian, and the third fauna in his Upper Silurian formations. While the broad land-marks remain as they were first set up by Murchison and Barrande, various modifications of nomenclature have since been proposed, to which allusion has already been made (p. 917). By general consent the strata containing the fossils of the first fauna or Primordial zone are embraced under Sedgwick's term Cambrian. As above remarked, Murchison's "Lower Silurian" has by many writers been replaced by "Ordovician," and his "Upper Silurian" is in a similar manner being ousted by some other term, so that if this process of substitution is perpetuated, the names given by the illustrious author of the "Silurian system" will disappear from current geological literature. I shall continue to employ Murchison's terminology, which has the claim of priority, and in my opinion is perfectly sufficient for the requirements of science.

§ 1. General Characters.

Rocks.—The Silurian system consists usually of a massive series of greywackes, sandstones, grits, shales, or slates, with occasional bands of limestone. The arenaceous strata include pebbly grits and conglomerates, which are specially apt to occur at or near any local base of the formation, where they rest unconformably on older rocks. Occasional zones of massive conglomerate occur, as among the Llandovery rocks of Britain. The argillaceous strata are in some regions (Livonia, &c.) mere soft clays: most commonly they are hard fissile shales, but in those areas

(Wales, &c.), where they have been subjected to the intensest compression, they appear as hard cleaved slates, or even as crystalline schists (Norway). In Europe, the limestones are, as a rule, lenticular, as in the examples of the Bala, Aymestry, and Dudley bands, though in the basin of the Baltic some of the limestones have a greater continuity. In North America, on the other hand, the Trenton limestone in the Lower, and the Niagara limestone in the Upper Silurian division are among the most persistent formations of the eastern United States and Canada, while in the Western Territories vast masses of Silurian limestone constitute nearly the whole of the system. Easily recognisable bands in many Silurian tracts, especially in the north-west of Europe, are certain dark anthracitic shales or schists, which, though sometimes only a few feet thick, can be followed for many leagues. As they usually contain much decomposing iron-disulphide, which produces an efflorescence of alum, they are known

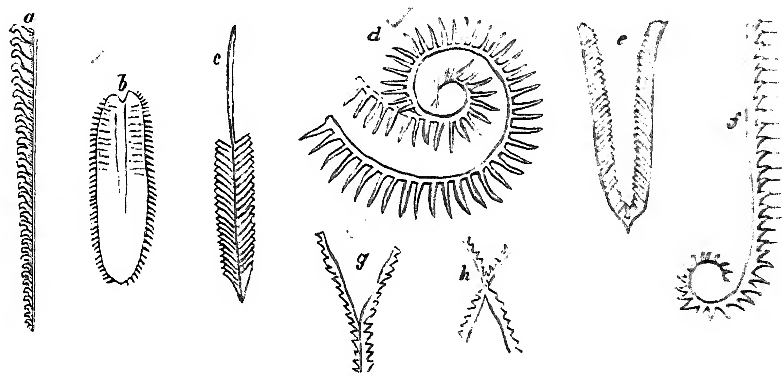

Fig. 376.—Group of Silurian Graptolites.

a, Monograptus priodon, Bronn (Wenlock); b, Phyllograptus typus, Hall (Lower Arenig); c, Diplograptus folium, His. (Llandovery); d, Rastrites peregrinus, Barr (Llandovery); e, Didymograptus Murchisoni, Beck. (Llandeilo); f, Monograptus Sedgwickii, Portl. (Llandovery); g, Dicranograptus ramosus, Hall (Llandeilo); h, Tetragraptus Hicksii, Hopk. (Lower Arenig).

in Scandinavia as the alum-slates. In Scotland, they are the chief repositories of the Silurian graptolites. Their black, coal-like aspect has led to much fruitless mining in them for coal. In the northern part of the State of New York, a series of beds of red marl with salt and gypsum occurs in the Upper Silurian series. Still more ancient is the group of saliferous and gypseous strata in the Salt Range of the Punjab, which has been above (p. 933) referred to as enclosing relics of the Primordial zone in the Cambrian system. In Styria and Bohemia, important beds of oolitic hæmatite and siderite are interstratified with the ordinary greywackes and shales. Occasionally sheets of various eruptive rocks (rhyolites, andesites, diabases, diorites, &c.) occur contemporaneously imbedded or subsequently intruded in the Silurian rocks (Wales, Lake District, S. Scotland, S.E. Ireland, &c.), and, with their associated tuffs, represent the volcanic ejections of the time.

Inasmuch as Silurian rocks have suffered from all the subsequent geological revolutions which have affected the regions where they were deposited, they now appear inclined, folded, contorted, broken, and cleaved, sometimes even metamorphosed into crystalline schists. Only rarely, as in the basin of the Baltic and in New York, do they still remain nearly in their original undisturbed positions.

LIFE.—The general aspect of the life of the Silurian period, so far as it has been preserved to us, may be gathered from the following summary published by Bigsby in 1868—plants 82 species; amorphozoa 136; foraminifera 25: cœlenterata 507; echinodermata 500; annelida 154; cirripedes 8; trilobita 1611; entomostraca 318; polyzoa 441; brachiopoda 1650; monomyaria 168; dimyaria 541; gasteropoda 1253; cephalopoda 1454; pisces 37; class uncertain 12; total 8897 species. Barrande in 1872 published another census in which some variations are made in the proportions of this table, the total number of species being raised to 10,074. No recent conspectus of the Silurian fossils seems to have been published, but their number during the last thirty years has been considerably increased.

The plants as yet recovered are chiefly algæ. In many cases they occur as mere impressions, which, like those of the Cambrian system, are often probably not of vegetable origin at all, but casts of the trails or burrows of worms, crustacea, &c.[1] Among the most abundant genera are *Bythotrephis*, *Arthrophycus*, *Palæophycus*, and *Nematophycus* (Carruth.). Remains of calcareous algæ, however, have been detected (Lower Silurian *Solenopora*, *Rhabdoporella*). The Upper Silurian rocks of Edinburghshire have yielded beautifully preserved specimens of an organism believed by Salter to be a sea-weed like the living *Gelidium* or *Plocamium*, which he named *Chondrites verisimilis*.[2] Traces, however, of what may have been a higher vegetation have been discovered, which are of special interest as being possibly the earliest known remains of a land-flora. Many years ago certain minute bodies (*Pachytheca*) in the Ludlow bone-bed were regarded as lycopodiaceous spore-cases, but doubt has been cast on their organic grade, and it has been suggested that they may even prove to belong to an alga. Hicks obtained from the Denbighshire grits of N. Wales what he considered to be spores and dichotomous stems, that were probably lycopodiaceous (*Berwynia*).[3] True lycopods (*Lepidodendron* or *Sagenaria*) have been met with in what are

[1] *Ante*, p. 911. Nathorst (*Kongl. Svensk. Vet. Akad. Handl.* xviii. (1881) has imitated some of these markings by causing crustacea, annelids, and mollusks to move over wet mud and gypsum, and has thus shown the high probability that they are not plants. (See *Geol. Mag.* 1882, pp. 22, 485; 1883, pp. 33, 192, 286.). Nathorst's opinion, adverse to the plant nature of the markings, is strongly opposed by Saporta in his 'À propos des Algues Fossiles,' 1882.

[2] The reference of this genus to sea-weeds has been questioned. A somewhat similar fossil (*Odontocaulis*) from Central Wales has been described as a dendroid graptolite, A. C. Seward, 'Fossil Plants,' 1898, p. 147. E. Stolley has described a number of siphoneous algæ obtained from Silurian boulders in the North German Drift, *Neues Jahrb.* 1893, ii. p. 135.

[3] *Q. J. G. S.* 1881, p. 482; 1882, pp. 97, 103. The vegetable nature of these remains is perhaps doubtful.

to be Upper Silurian rocks in Bohemia. The Tanne Greywacke of Harz and adjacent districts has yielded a number of land-plants, ...ding ferns (*Sphenopteridium*, two or more species), and others ...red to *Cyclostigma* (*C. hercynium*), *Stigmaria*, *Asterocalamites ?*, ...opsis, &c.[1] From the Clinton limestone of Ohio a portion of what ... a lepidodendroid tree (*Glyptodendron eatonense*) has been obtained. Cincinnati and Lower Helderberg groups of eastern North America ...aid to have yielded a microcosmical representation of the Carboni- ... flora.[2] The land of the Silurian period probably had a cryptogamic ...tation in which lycopods and ferns played the chief part.[3]

In the fauna of the Silurian rocks, the most lowly organisms known ...raminifera, of which several genera, including the still living genera ... and *Saccammina*, have been detected. Certain layers of chert, ...ly spread over the south of Scotland, have yielded upwards of a ...n genera with more than twenty species of Radiolaria.[4] The Silurian possessed representatives of the siliceous sponges of modern times. ...lithistid forms are exemplified in the *Aulocopium*, *Astylospongia* and ...spongia of the Lower, and in the *Caryomanon* and *Hindia* of the ...per Silurian series. The hexactinellid types appear in genera belong- ... the Dictyospongidæ, the Plectospongidæ, and the genera *Amphi-* ...*, Astroconia*, *Hyalostelia*, and *Astræospongia*. Of the puzzling genera ...*ylaculites* and *Ischadites*, the true relationships have not yet been de- ...ined. They have been considered by some as algæ, by others as ...minifers, and by Dr. Hinde as sponges. *Nidulites*, too, though a com- ... fossil, is still a subject of uncertainty as to its organic grade, the ... view being that it may be related to the polyzoa.

Corals must have swarmed on those parts of the Silurian sea-floor on ...h calcareous accumulations gathered, for their remains are abundant ...g the limestones, particularly in the upper division of the system. ...ugose corals make their appearance in the Lower and reach their ...mum development in the Upper Silurian rocks. They are repre- ...ed by numerous genera and species (*Streptelasma*, *Cyathophyllum*, ...*phyllum*, *Petraia*, *Omphyma*, *Cystiphyllum*, *Strombodes* (*Arachnophyllum*), ...*nlaria* (Fig. 381). Perforate corals were represented by *Calostylis* ... *Protaræa*. Numerous tabulate types occur (*Favosites*, *Calapoecia* = ...*mopora*, *Pachypora*, *Syringolites*, *Alveolites*, *Cladopora*, *Syringopora*, ...*tes* or chain-coral), and are regarded by recent writers as Alcyo- ...rians. *Monticulipora* may also be an Alcyonarian, but is referred by ... authors to the Polypora. *Heliolites* is a conspicuous form, and ...mbles the living Alcyonarian *Heliopora*. So abundant were some of

1 H. Potonié, *Abhand. K. Preuss. Geol. Landesanst*, Neue Folge, Heft 36 (1901).

2 L. Lesquereux, *Amer. Journ. Sci.* (3), vii. p. 31 ; *Proc. Amer. Phil. Soc.* xvii. p. 163.

3 Zeiller, however, in his recent Text-book remarks that the evidence for the existence of ...ants in the Silurian period of higher grade than algæ is exceedingly meagre. The ... will find a valuable compendium of information by L. F. Ward regarding the fossil ... past time all over the world in the 8*th Ann. Rep. U.S. G. S.* Part ii. 1889.

4 G. J. Hinde, *Ann. Mag. Nat. Hist.* 1890, p. 40 ; *Q. J. G. S.* lv. (1899), p. 214, and David and Pittman in same volume, p. 16.

the corals on the floor of the Silurian sea as to form reefs there, composed almost wholly of their calcareous skeletons, mingled with remains of crinoids, bryozoa, and mollusks.

The Hydrozoa were abundant in the waters of Silurian time. The Stromatoporoids helped by their aggregates to form sheets of limestone. The plant-like branching *Dictyonema* (*Dictyograptus*) we have found to be characteristic of the strata at the top of the Cambrian or base of the Silurian system. But it was by the great extinct tribe of the Graptolites that the Hydrozoa were most fully represented. As already stated, these organisms are so characteristically Silurian that they serve to distinguish the Silurian from other formations. Some of them are monoprionidian forms, that is, are furnished with a single row of cells; others are diprionidian, or possess two rows of cells, while in some genera both these features are united, as in *Dicranograptus*, where two single-celled branches are given off from a double-celled stem. The genera *Monograptus* (of which upwards of forty species have been found in Britain), *Rastrites* and *Cyrtograptus* are characteristic of Upper Silurian, *Leptograptus*, *Stephanograptus* (= *Coenograptus*), *Didymograptus*, *Phyllograptus*, *Lasiograptus*, *Tetragraptus*, *Dichograptus*, *Dicellograptus* and *Dicranograptus* of Lower Silurian rocks. *Diplograptus*, *Climacograptus*, and *Retiolites* are found both in Lower and Upper Silurian strata. Through the researches chiefly of Professor Lapworth it has been ascertained that the species are confined within comparatively narrow limits, although some of the genera have a considerable vertical range, and hence that graptolites may be used to mark definite palæontological horizons.[1] He has enumerated twenty recognisable graptolite zones, one in the Upper Cambrian, eight in the Lower Silurian, and eleven in the Upper Silurian formations.[2]

The Echinoderms of the Silurian seas were extremely abundant in individuals as well as varied in genera and species. They comprised representatives of the great divisions of this sub-kingdom. The Crinoids or sea-lilies appear among the Lower Silurian formations in the genera *Reteocrinus*, *Archæocrinus*, *Glyptocrinus*, *Hybocrinus*, *Anomalocrinus*, *Heterocrinus*, *Castocrinus*, *Dendrocrinus*, and the Upper Silurian forms include *Dimerocrinus* (*Thysanocrinus*), *Cyphocrinus* (*Hyptiocrinus*), *Lyriocrinus*, *Melocrinus*, *Calceocrinus*, *Gissocrinus*, and many more. The Cystideans, as already stated, attained their maximum development during Silurian time, scarcely a dozen of the 250 described species being found above the Silurian system. Among the genera may be mentioned *Aristocystites*,[3] *Sphæronites*, *Echinosphærites*, *Cryptocrinus*, *Glyptocystites*, *Pleurocystites*, which occur in Lower Silurian strata, and *Megacystites* (*Holocystites*), *Caryocrinus*, *Pseudocrinus*, *Lepadocrinus* (*Apiocystites*) in the Upper division. The Blastoids are represented by the primitive forms *Asteroblastus* and

[1] The student should consult Professor Lapworth's monograph, "On the Geological Distribution of the Rhabdophora" (*Ann. Mag. Nat. His.* ser. 5, vols. iii. iv. v. and vi. 1879, 1880), in which the geological significance of the graptolites is fully discussed.

[2] *Op. cit.* vol. v. (1880), p 197.

[3] It should be mentioned that some palæontologists would shorten these generic names thus: *Aristocystis*, *Sphæronis*, *Echinosphæra*, &c.

Troostocrinus in the Upper Silurian series of North America. There were likewise early forms of ophiuroid or brittle-star (*Eucladia, Lapworthura, Protaster*, Upper Silurian) and of asteroidea or star-fishes (*Palæaster, Palæocoma, Lepidaster*). The earliest known sea-urchins are met with in Lower Silurian strata (*Bothriocidaris*), and others belonging to the genera *Palæechinus* and *Echinocystis* are found in the upper division of the system. The Annelids of the Silurian sea-bottom comprised representatives of both the tubicolar and errant orders. To the former belong some species of the still living genera *Spirorbis* and *Serpula*, together with some forms doubtfully referred to this division of the animal kingdom (*Cornulites, Ortonia, Conchicolites, Serpulites*). The errant forms are known chiefly by their burrows or trails, which appear in immense profusion on the surfaces of shales and sandstones (*Arenicolites, Nereites, Scolithus, Crossopodia*, &c.), but also by their jaws, which occur in great numbers in the Wenlock and Ludlow rocks.[1]

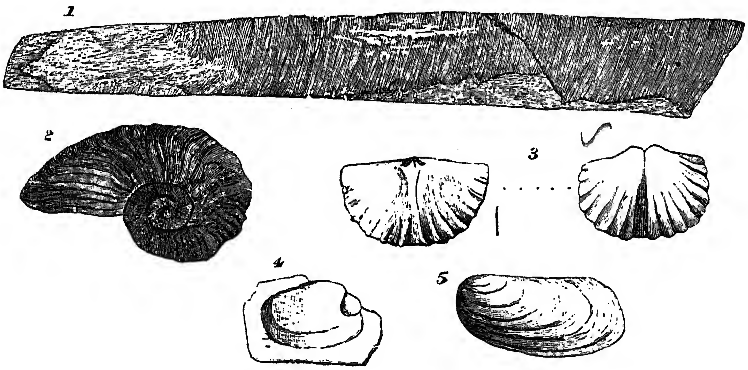

Fig. 377.—Group of Arenig Fossils.
1, Orthoceras cæreesiense, Hicks; 2, Bellerophon llanvirnensis, Hicks; 3, Orthis calligramma, Dalm. (enlarged); 4, Redonia anglica, Salt.; 5, Palæarca amygdalus, Salt.

The Bryozoa or Polyzoa appear in considerable number and variety in the Lower Silurian formations, where they occur in cyclostomatous (*Stromatopora, Diastoporina, Protocrisina, Mitroclema, Ceramoporella, Fistulipora*), trepostomatous (*Monticulipora, Heterotrypa, Callopora, Trematopora, Constellaria, Bythopora, Amplexopora*, &c.) and cryptostomatous forms (*Ptilodictya, Rhinidictya, Arthrostylus, Fenestella, Phylloporina*).

The Brachiopods attained their maximum diversity and importance during the Silurian period. From the deposits of that time upwards of 2600 species have been named. They include representatives of all the orders. The atrematous forms are shown by species of *Dinobolus, Lingula*, &c.; the neotremata by *Acrotreta, Siphonotreta, Trematis, Orbiculoidea, Schizotreta, Crania*, &c.; the protremata by many genera, including *Eichwaldia, Leptæna, Strophomena, Chonetes, Orthis* (Fig. 377, of which about 400 Silurian species are known), especially abundant in the Lower

[1] G. J. Hinde, *Q. J. G. S.* 1880, p. 368; *Bihang. Svensk. Vet. Akad. Handl.* vi. (1882).

division; *Clitambonites*, *Porambonites* (Lower Silurian), *Stricklandinia*, *Pentamerus* (Upper Silurian), and the telotremata by some primitive forms of the Rhynchonellids (*Protorhyncha*), by more typical genera of that family (*Orthorhynchula*, *Rhynchotreta*, without any species of the actual genus *Rhynchonella*, which probably did not make its appearance until after Palæozoic time) and by a number of Spiriferid genera (*Atrypa*, *Zygospira*, *Spirifer*, *Cyrtia*, *Homœospira*, *Meristina*).

Every one of the five classes of the sub-kingdom Mollusca had its representatives in the Silurian seas.[1] Among the Lamellibranchs may be enumerated *Orthonota*, *Vlasta*, *Grammysia*, *Antipleura*, *Præcardium*, *Ctenodonta*,* *Nucula*, *Nuculana* (=*Leda*), *Cyrtodonta*, *Pterinea*, *Lyrodesma*, *Modiolopsis*,* *Allodesma*.* The Scaphopods appear in species which closely resemble the living *Dentalium*, the Amphineura in one or two genera of Chitons (*Helminthochiton*, *Priscochiton**). The Gasteropods show a marked increase in variety and number of species over their Cambrian predecessors. They are still comparatively simple in structure, and include some primeval limpets. Characteristic genera are *Metoptoma*, *Lepetopsis*, *Palæacmæa*, *Tryblidium*, *Pleurotomaria*,* *Raphistoma*,* *Cyrtolites*,* *Bellerophon*, *Platyschisma*, *Euomphalus*, *Maclurea*,* *Omphalotrochus*,* *Cyclonema*,* *Macrocheilus*, *Scalites*,* *Holopea*,* *Platyostoma*, *Tentaculites*,* *Pterotheca*, *Conularia*.*

That the salt waters of the Silurian era swarmed with Cephalopods may be inferred from the fact that, according to Barrande's census, no fewer than 1622 species had then been described. They are all tetrabranchiate, and include all the suborders of the Nautiloidea. Those of the holochoanite (*Diphragmoceras*,* *Vaginoceras*,* *Endoceras*,* *Piloceras*,* *Cyrtendoceras**) and of the mixochoanite divisions (*Choanoceras*,* *Aphragmites*, *Ascoceras*, *Glossoceras*) are distinctively Silurian, and die out in this system. The orthochoanite forms, of which the living nautilus is an example, abounded in numbers and variety of types. The genus *Orthoceras* was especially conspicuous; Barrande described upwards of 550 species from the basin of Bohemia alone. Among the other types mention may here be made of *Cycloceras*,* *Ctenoceras*,* *Kionoceras*, *Deltoceras*,* *Lituoceras*,* *Discoceras*,* *Plectoceras*,* *Ophidioceras*, *Lituites*,* *Hercoceras*, *Loxoceras*,* *Actinoceras*,* *Jovellania*, *Rizoceras*, *Ooceras*, *Oncoceras*,* *Poterioceras*,* *Trimeroceras*, *Phragmoceras*, to which many other genera might be added.

Crustacea are abundantly represented among the Silurian formations, more especially by the extinct tribe of the Trilobites. These organisms had already attained a considerable development in Cambrian time, but it was in the early part of the Silurian period that they reached their maximum in numbers and variety. Thereafter they appear to have rapidly declined during the Upper Silurian and Devonian ages, dying out finally in Permian time. A few of the Cambrian genera survived in the Silurian waters (*Agnostus*, *Asaphus*, *Cheirurus*). But a host of new forms made their appearance. Among these the following genera are character-

[1] The genera marked with an asterisk are found in the Lower Silurian formations, but some of them are certainly or probably also Cambrian, such as *Ctenodonta*, *Pleurotomaria*, *Raphistoma*, *Cyrtolites*, *Bellerophon*, *Ogygia*, *Cheirurus*, *Leperditia*, *Beyrichia*, *Primitia*, and *Ceratiocaris*; those with no sign have been met with in the Upper only.

istic: *Harpes,** *Trinucleus,** *Triarthrus,** *Ogygia,** *Illænus,** *Lichas,** *Acidaspis,** *Encrinurus,** *Placoparia,** *Calymene,** *Cheirurus,** *Sphærexochus,** *Phacops*, *Trimerocephalus*. Some of the genera of trilobites are world-wide in their range, such as *Agnostus*, *Conocoryphe*, *Paradoxides*, *Trinucleus*, *Asaphus*, *Illænus*, *Acidaspis*, *Lichas*, *Calymene*, *Cheirurus*, *Phacops* and some others. "The majority of forms, however, are extremely limited in distribution, so that a large number of genera found in Sweden, Bohemia, England and North America, are unknown outside very restricted areas; and the total number of species common to both sides of the Atlantic is very small."[1] The bearings of this subject on the discussion of Silurian geography will be referred to a little farther on.

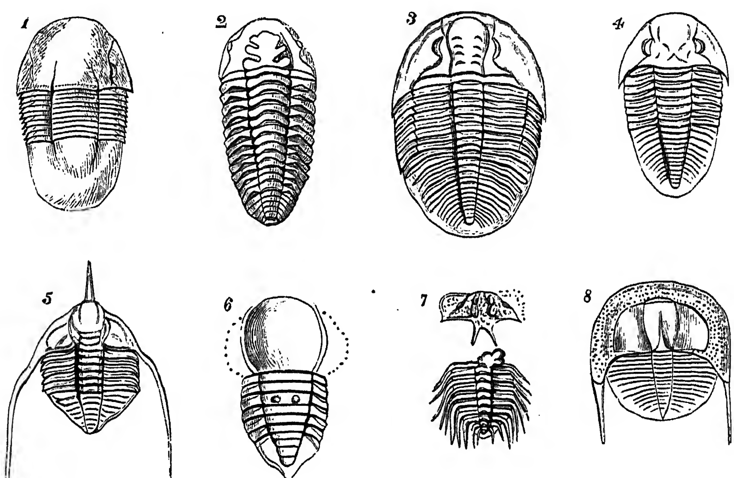

Fig. 378.—Group of Lower Silurian Trilobites.

1, Illænus Davisii, Salt. ($\frac{1}{2}$); 2, Calymene brevicapitata, Portl.; 3, Ogygia Buchii, Brongn. ($\frac{1}{4}$); 4, Asaphus tyrannus, Murch. ($\frac{1}{11}$); 5, Ampyx nudus, Murch. ($\frac{1}{2}$); 6, Æglina binodosa, Salt.; 7, Acidaspis Jamesii, Salt.; 8, Trinucleus Lloydii, Murch.

The Ostracod crustacea, which are first found in the upper part of the Cambrian system, reach a much greater abundance and variety among the Silurian formations, where they include the genera *Leperditia,** *Leperditella,** *Isochilina,** *Beyrichia,** *Primitia*, *Kloedinia,** and likewise some early cyprids (*Bairdia,** *Macrocypris,** *Pontocypris*) and *Cytherella*, *Entomis,** *Cypridina.** Early forms of barnacles are found in *Lepidocoleus** and *Turrilepas.** The Phyllocarid crustacea made a marked advancement in Silurian time, where they were represented by species of *Ceratiocaris,** *Physocaris*, *Discinocaris*, *Peltocaris,** and others. That the Amphipods had already come into existence in Silurian time has been supposed to be indicated by the *Necrogammarus* of the Ludlow group of strata, but this form may prove to be a myriapod.[2] The Merostomata, of which at least

[1] Zittel's 'Text-book of Palæontology,' i. (1900), p. 637.

[2] B. N. Peach, *Proc. Roy. Phys. Soc. Edin.* xiv. (1899), p. 113.

one form had already appeared in the Cambrian system, come into great prominence among the Upper Silurian formations. Besides a few Hemiaspidæ the important order of Eurypterids attains a striking development. Among its Silurian forms are species of *Eurypterus*, *Dolichopterus*, *Eusarcus*, *Slimonia*, *Stylonurus*, *Pterygotus*. Some of these organisms attained a gigantic size, specimens of *Eurypterus* measuring fifteen inches in length, *Stylonurus* sometimes nearly five feet,[1] while *Pterygotus* occasionally exceeds six feet.

The first traces of vertebrate life make their appearance in the Silurian system. They consist partly of the plates of a curious group of fish-like animals designated ostracoderms, the true organic grade of which is still matter of dispute, though they were formerly classed as fishes (*Pteraspis*, *Cyathaspis*, *Cephalaspis*, *Thyestis* = *Auchenaspis*), but since they seem to have been without a lower jaw, they are regarded by some writers as below the rank of true fishes. They are distinguished by the great strength of their bony covering. The bone-bed of the Ludlow rocks long ago yielded certain curved fin-spines (*Onchus*) of an elasmobranch, which resemble the dorsal spines of the living *Cestracion*, and some shagreen-like plates which have been supposed to be scales of ostracoderm fishes (*Sphagodus*, *Thelodus*), and bodies like jaws with teeth which were called *Plectrodus*, but which are now known to be lateral shield-spines of a cephalaspidean form (*Eukeraspis*). It is probable that some of these remains have been incorrectly determined, and may belong to crustaceans or annelides. The so-called "Conodonts" (*ante*, p. 913) of the older Palæozoic rocks of Europe and North America, originally supposed to be the teeth of such fishes as the lamprey, which possessed no other hard parts for preservation, have been also referred to different divisions of the invertebrata, but palæontologists now regard them as probably in most cases the jaws of annelids.[2] Recently some remarkable discoveries of true fishes have been made by the Geological Survey in the uppermost group of the Upper Silurian formations of Central Scotland. A number of small shark-like fishes have there been found belonging in some cases to new genera (*Lanarkia*, *Birkenia*, *Lasanius*), together with new species of the old genus *Thelodus*. Some of these forms (*Lanarkia*) were diminutive, from two to five inches long, covered with a shagreen of small pointed and striated spines. The *Birkenea* is a new type which, though its head is covered with narrow scutes instead of a large shield, resembles *Cephalaspis*, and like it may belong to the Ostracoderms.[3]

Up to the present time no trace has been detected of any vertebrate land-animals of Silurian age. In Sweden, France, Scotland, and the

[1] For a restoration of this form, see *Geol. Mag.* 1900, p. 481.

[2] Zittel and Rohon, *Sitzb. Bayr. Akad.* Munich, 1886, p. 108. According to Dr. Rohon, however, all "Conodonts" are not annelidian, but include undoubted teeth of fishes with recognisable dentine, enamel, and pulp-cavity (*Bull. Acad. St. Petersb.* xxxiii. (1890), p. 269). A valuable work of reference is the British Museum 'Catalogue of Fossil Fishes.'

[3] R. H. Traquair in *Summary of Progress of Geological Survey* for 1897, p. 72; and *Trans. Roy. Soc. Edin.* xxxix. (1899), pp. 827-864.

United States, however, the discovery of remains of arachnid and insect life in Silurian rocks may herald the ultimate detection of higher forms of life. In the Upper Silurian strata of the island of Gothland a true scorpion has been discovered, which appears to differ but little from recent forms, though in its walking legs it was of a more primitive type. It was believed by its original describer to possess breathing stigmata, and thus to have been an air-breather.[1] Later research, however, appears rather to indicate that the creature possessed no stigmata, but probably breathed by gills and was aquatic.[2] Subsequently more perfect examples of the same genus (*Palæophonus*) were described by Mr. Peach from the Upper Silurian rocks of Lesmahagow, Lanarkshire (Fig. 383). The presence of a poison-gland and sting at the extremity of the tail indicates that, like their modern representatives, these animals preyed on other denizens of land or water. Soon after the European discoveries, the finding of a scorpion (*Proscorpius*) in the "Waterlime" (Upper Silurian) of New York was announced.[3] These specimens seemed to lift the veil that had concealed from us all evidence of the terrestrial fauna of this ancient period of geological history. If there were true scorpions on the land, there were almost certainly other land-animals on which they lived. Mr. Peach has suggested that they may have fed partly on marine crustacean eggs left bare by the tides.[4] A myriapod (*Archidesmus*) has been found in the Upper Silurian rocks of Lanarkshire. That true insects also existed has been made known by the discovery of an orthopterous wing (*Palæoblattina*) in the Lower Silurian (probably Caradoc) sandstone of Jurques, Calvados.[5] It measures about $1\frac{1}{3}$ inch long, and is distinguished by the length of the anal nervure and the small breadth of the axillary area. A hemipterous wing (*Protocimex*) has since been obtained from the lower graptolite shales of Sweden.[6] We may be confident that these are not the only relics of the Silurian terrestrial fauna that have been preserved, and we may hope that still more remarkable treasures are yet to be unearthed from their primeval resting-places.

A survey of the general character and geographical distribution of the earliest known fauna suggests some interesting reflections regarding the climate and physical geography of the earth during the long lapse of time denoted by the Cambrian and Silurian formations. The profusion of corals in some of the limestones, which may be regarded as equivalents of modern reefs, suggests that the temperature of the ocean was generally warmer in extra-tropical regions than it is now. We cannot, indeed, affirm with certainty that the Palæozoic reef-builders, like their living representatives, required a temperature of not less than 68° Fahr. But in the absence of any indication to the contrary it may be assumed that

[1] G. Lindström, *Comptes rend.* xcix. (1884); T. Thorell and G. Lindström, *K. Svensk. Vet. Akad. Handl.* xxi. No. 9 (1885).

[2] Pocock, *Quart. Jour. Micro. Science*, xliv. (1901), p. 291.

[3] R. P. Whitfield, *Science*, vi. (1885), p. 87.

[4] B. N. Peach, *Nature*, xxxv. (1885), p. 295; *Trans. Roy. Soc. Edin.* xxx. (1882).

[5] Ch. Brongniart, *Comptes rend.* xcix. (1884), p. 1164; *Geol. Mag.* 1885, p. 481.

[6] J. C. Moberg, *Geol. Fören. Stockholm*, xiv. (1892), p. 122.

they did. In that case we see that even up to as high a latitude as North Devon (75° N.), where Silurian coral-limestones have been observed, the waters of the ocean were comparatively warm. This inference is strengthened by the remarkable extension of the Silurian fauna over a large part of the surface of the globe. The assemblage of organisms at the base of the Silurian system (the Euloma-Niobe-fauna), which extends from Swedish Lapland to Languedoc, shows, as Professor Brögger has pointed out, that no marked difference of temperature can have existed between the 43rd and 65th parallels of north latitude.[1] The Silurian fauna has been detected even as far north as Northern Greenland and Grinnell Land above latitude 80°. It spreads likewise into the southern hemisphere, where, in Tasmania, Victoria, South Australia, and New Zealand, some of the characteristic genera, and even some of the well-known species of Europe and North America, have been obtained. This world-wide diffusion may be taken to indicate the prevalence of a tolerably uniform and probably rather warm temperature over the globe even far up into Arctic latitudes.

While a number of the Cambrian and Silurian species are of universal occurrence, there is sufficient diversity between the faunas of certain geographical areas not far removed from each other to indicate a want of direct connection between the seas in which these organisms lived, and thus to furnish us with some clue to the probable distribution of sea and land during early Palæozoic time. Allusion has been made above to the local character of many of the trilobites, and the small number of species that appear to have migrated between the Old World and the New. This contrast comes out even between the faunas of neighbouring tracts of the same continent. In Europe, for example, a striking difference has been remarked between the older Palæozoic trilobites of the northern and north-western countries and those of the central region. "While the majority of northern genera and species are common to Great Britain, Scandinavia, and Russia, the forms of the central European provinces, (Bohemia, Thuringia, Fichtelberg, the Hartz, Belgium, Brittany, Northern Spain, Portugal, the Pyrenees, the Alps and Sardinia) are so dissimilar as to stand in closer relationships with the North American than with the first-named trilobite fauna. Of the 350 species found in Norway and Sweden, and of the 275 in Bohemia, only six are common to both provinces, and it is doubtful if these are really identical."[2] A somewhat similar contrast has been noted in North America between the general Upper Silurian fauna of the Mississippi valley and that of the State of New York. The former includes a number of peculiar and highly specialised forms, which it shares with Northern Europe, but which are not found in the Upper Silurian strata of New York, such as the crinoids *Crotalocrinus*, *Clonocrinus* (*Corymbocrinus*), *Pycnosaccus* and *Petalocrinus*, the coral *Goniophyllum*, and the peculiar little twisted brachiopod *Streptis*. Mr. Weller infers that the Silurian sea, which was directly connected with Europe, stretched from the north in a long tongue down the heart of the

[1] *Nyt. Mag.* xxxvi. (1898), p. 236.

[2] Zittel's 'Text-book of Palæontology,' vol. i. p. 637.

American continent, and was not immediately united to the waters in which the New York fauna lived.[1]

From evidence of this kind, carefully collected and collated, the geography of former geological periods may be in some measure reconstructed. Various tentative efforts in this direction have been made, but much fuller information is required before the results can be regarded as based more on ascertained fact than on ingenious conjecture.

§ 2. Local Development.

Britain.[2]—In the typical area where Murchison's discoveries were first made, he found the Silurian rocks divisible into two great and well-marked series, which he termed Lower and Upper. This classification has been found to hold good over a large part of the world. The subjoined table shows the arrangement and nomenclature of the various subdivisions of the Silurian system :—

			Feet.
UPPER SILURIAN.	3. Ludlow group .	approximate average thickness	1900
	2. Wenlock group .	,,	1600
	1. Llandovery group	,,	2500
LOWER SILURIAN.	3. Caradoc or Bala group	,,	6000
	2. Llandeilo group	,,	2000
	1. Arenig group .	,,	2000

LOWER SILURIAN.—The typical subdivisions in Wales and Shropshire will first be described, and afterwards the development of the series in other parts of Britain. It will be remembered that on the ground of the palæontological evidence the Tremadoc group (p. 921) might be most fitly placed at the base of the Silurian system, but that in deference to long established usage it has here been retained in its old place at the top of the Cambrian series. We see in it the advent of the rich trilobitic fauna by which the Silurian formations are distinguished, the Asaphidæ, Trinucleidæ, Cheiruridæ, and other tribes. Beneath it only a few graptolites are found, and hardly any cephalopods, but above it graptolites come in with extraordinary variety and number, and cephalopods rapidly increase also in importance among the fossils.

1. Arenig Group.—These rocks consist of dark slates, shales, flags, and bands of sandstone, which pass down conformably into the Tremadoc group of the Cambrian series. They are abundantly developed in the Arenig mountain, where, as originally described by Sedgwick, they include masses of associated volcanic rocks. In their abundant suite of organic remains (Fig. 377) new genera of trilobites make their appearance (*Æglina*, *Barrandia*, *Calymene*, *Homalonotus*, *Illænopsis*, *Illænus*, *Phacops*, *Placoparia*, *Trinucleus*). Pteropods are represented by species of *Conularia* and *Hyolithes*; brachiopods by *Lingula*, *Lingulella*, *Monobolina* (*Obolella*), and *Orthis*; lamellibranchs by *Palæarca*, *Redonia*, and *Ribeiria*; gasteropods by *Ophileta*, *Pleurotomaria*, *Bellerophon*, and *Maclurea*; and cephalopods by *Orthoceras*. But the most abundant organisms are the graptolites, of which no fewer than twenty genera have been found in the Arenig rocks of Britain.

Professor Lapworth divides the Arenig group into two parts, a Lower and an Upper, and he states that in the lower part the genus *Tetragraptus* (Fig. 376), is especially

[1] S. Weller, *Journ. Geol.* vi. (1898), pp. 692-703.

[2] See Murchison's 'Silurian System,' and 'Siluria'; Sedgwick's 'Synopsis' (cited p. 915); Ramsay's "North Wales" in *Memoirs of Geol. Surv.* vol. iii.; Etheridge, Address, *Q. J. G. S.* 1881; numerous local memoirs in the *Q. J. G. S.* and *Geol. Mag.*, particularly by Hicks, Ward, Hughes, Keeping, Lapworth, &c., to some of which reference is made in subsequent pages.

characteristic, and does not occur on any higher or lower horizon. Here he places the lowest Silurian graptolitic zone, that of *Tetragraptus serra* (*bryonoides*). The genera *Loganograptus*, *Clonograptus*, *Schizograptus*, and *Dichograptus* are probably also peculiar to the same strata, as well as the species *Didymograptus extensus*, *D. pennatulus*, and the only known examples of *Retiograptus*. According to this classification, the upper part of the Arenig group (zone of *Didymograptus bifidus*) is especially marked by the presence of *Phyllograptus* (Fig. 376), in association with forms of *Didymograptus* like *D. bifidus*. Species peculiar to it, besides the last-named, are *D. minutus* and some forms of Diplograpta, such as *Climacograptus confertus*.[1]

Hicks and others have recognised three divisions in the Arenig group—Lower, Middle, and Upper. The lower contains two genera found in the Tremadoc group below (*Dictyograptus* and *Dendrograptus*), and is also characterised by the presence of *Didymograptus extensus*, *D. pennatulus*, *Phyllograptus stella*, and *Trigonograptus*. The middle division is marked by *Tetragraptus serra*, *T. quadribrachiatus*, &c., while the upper includes several species of *Didymograptus* (*D. bifidus*, *D. patulus*, &c.), *Climacograptus confertus*, and *Diplograptus dentatus*.[2]

Hicks proposed to construct a separate group under the name of "Llanvirn," by taking the upper part of the Arenig (*Didymograptus bifidus* zone) and lower portion of the Llandeilo rocks, making a total thickness of about 2000 feet of strata near St. David's in South Wales.[3] It is in this group of strata that the trilobites *Acidaspis*, *Barrandia*, *Illænus*, and *Phacops* make their earliest appearance. Sir A. C. Ramsay believed that in North Wales there is an unconformable overlap of the Arenig upon the Tremadoc and older beds; but in South Wales there does not appear to be any break.[4]

A remarkable feature in the history of the Arenig rocks in Wales was the volcanic action during their formation, whereby various felsitic or rhyolitic lavas, with abundant discharges of fine ashes and coarser agglomerates, were erupted over the sea-bottom and interstratified with the contemporaneously deposited sediments, while more basic sills were subsequently injected under the volcanic sheets. Some of the more important Welsh mountains consist mainly of these ancient volcanic materials—Cader Idris, the Arans, Arenig Mountain, and others.[5]

2. Llandeilo Group.—These dark argillaceous and occasionally calcareous flagstones, sandstones, and shales were first described by Murchison as occurring at Llandeilo, in Carmarthenshire. They reappear near St. David's, on the coast of Pembrokeshire, and at Builth, in Radnorshire.[6] In the middle of them a seam of limestone (Llandeilo limestone) occurs, while intercalated igneous rocks are specially noticeable in the upper subdivision. It was at one time believed that graptolites were almost confined to this group. These fossils, now known to range from the Cambrian to the top of the

[1] Lapworth, *Ann. Mag. Nat. Hist.* vol. vi. (1880), p. 197.

[2] Hicks, *Q. J. G. S.* xxxi. (1875), p. 171; Hopkinson and Lapworth, *ibid.* pp. 634-637.

[3] *Pop. Science Rev.* (1881), p. 289.

[4] "Geology of N. Wales," *Mem. Geol. Surv.* iii. On the Arenig, Llanvirn, and Llandeilo series of Caermarthen in South Wales, Misses Crosfield and Skeat, *Q. J. G. S.* lii. (1896), p. 523.

[5] For descriptions of the Arenig lavas and tuffs consult the "Geology of N. Wales," already cited; also G. A. Cole and C. V. Jennings, *Q. J. G. S.* xlv. (1889); *Geol. Mag.* (1890), p. 447. Jennings and G. J. Williams, *Q. J. G. S.* xlvii. (1891), p. 374. A. G. *op. cit.* Presid. Address, p. 105; and 'Ancient Volcanoes of Great Britain,' vol. i. The Lower Silurian rocks of the Shropshire area (where the position of the Shelve quartzite was recognised by Murchison) are described by Lapworth, *Geol. Mag.* 1887, p. 78; *Proc. Geol. Assoc.* 1894, p. 317.

[6] The interesting volcanic series at Builth is described by Mr. H. Woods, *Q. J. G. S.* l. (1894), p. 566. Lower Llandeilo lavas and the Llanvirn fauna have been recognised by Mr. F. R. Cowper Reed at Fishguard on the Pembrokeshire coast, *op. cit.* li. (1895), p. 149.

Silurian system, occur abundantly in the Llandeilo rocks, and present there a transitional character between the Arenig types below and those in the Caradoc or Bala rocks above. In the lower portions of the group the most abundant genus is *Didymograptus*, *D. Murchisoni* (Fig. 376) being the characteristic species (and serving to mark a graptolitic zone), accompanied by many of the Arenig species, together with new forms of *Cryptograptus* and *Glossograptus*. In the middle part of the group the *D. Murchisoni* becomes very rare and is associated with *Diplograptus foliaceus* and *Climacograptus Scharenbergi*. In the Upper Llandeilo rocks graptolites of the type of *Cryptograptus tricornis* and *Climacograptus Scharenbergi* are abundant, also species of *Cœnograptus* with *Dicellograptus sextans* (zone of *Cœnograptus gracilis*). Trilobites are characteristic fossils of the group, upwards of fifty species belonging to eighteen or twenty genera being known. These include characteristic forms which do not range beyond the group, *Asaphus tyrannus* (Fig. 378, 4) *Calymene cambrensis*, *Trinucleus Lloydii* (Fig. 378, 8) and *T. favus* being found in the lower subdivision, and *Barrandia Cordai*, *Cheirurus Sedgwickii*, and *Ogygia Buchii* (Fig. 378, 3) in the upper. The brachiopods include the genera *Acrotreta*, *Crania*, *Discina*, *Siphonotreta*, *Leptæna*, *Lingula*, *Orthis*, *Plectambonites*, and *Strophomena*, some of which here make their first appearance. The lamellibranchs are represented by species of *Cardiola* (*C. interrupta?*) and *Modiolopsis* (*M. expansa*, *M. inflata*), the gasteropods by *Cyclonema*, *Euomphalus*, *Murchisonia*, *Pleurotomaria*, *Raphistoma*, *Bellerophon*, *Ecculiomphalus*, and *Maclurea*, the pteropods by *Conularia* and *Hyolithes*, the cephalopods by *Cyrtoceras*, *Orthoceras*, and *Endoceras*.

3. Caradoc or Bala Group.—Under the first name were placed by Murchison the thick yellowish and grey sandstones of Caer Caradoc in Shropshire, and the Horderley and May Hill Sandstone. It was afterwards ascertained that the grey and dark slates, grits, and sandstones described by Sedgwick as occurring round Bala in Merionethshire, and regarded by him as the higher part of his Cambrian system, were really slightly different lithological developments of the same stratigraphical division. In the Shropshire area, some of the rocks are so shelly as to become strongly calcareous. In the Bala district, the strata contain two limestones separated by a sandy and slaty group of rocks 1400 feet thick. The lower or Bala limestone (25 feet thick) has been traced as a variable band over a large area in North Wales. It is usually identified with the Coniston limestone of the Westmoreland region. The upper or Hirnant limestone (10 feet) is more local. Bands of volcanic tuff and large beds of various felsitic lavas occur among the Bala beds, and prove the contemporaneous ejection of volcanic products. These attain a thickness of several thousand feet in the Snowdon region.[1]

A large suite of fossils has been obtained from this group (Fig. 379). The sponges are represented by a few forms (*Astylospongia*). The graptolites are strongly differentiated from those of the Arenig rocks by the entire absence of Dichograptidæ and Phyllograptidæ. The Diplograptidæ, feebly represented in the Arenig and Lower Llandeilo groups, are now, as Professor Lapworth points out, the dominant forms, occurring in swarms in every zone. The two genera *Diplograptus* and *Climacograptus* are especially abundant. The following successive zones, each marked by the prevalence of its own species of graptolite, have been observed by Professor Lapworth in ascending order: (1) zone of *Climacograptus Wilsoni*, (2) zone of *Dicranograptus Clingani*, (3) zone of *Pleurograptus linearis*, (4) zone of *Dicellograptus complanatus*, (5) zone of *Dicellograptus anceps*. The same observer remarks upon the extraordinary extinction of families, genera, and species of graptolites during the period of the Caradoc-Bala rocks. "The entire families of the Dicranograptidæ, Leptograptidæ, and Lasio-

[1] For accounts of the volcanic phenomena of the Caradoc-Bala series of Wales, see Ramsay's 'Geology of North Wales,' already cited. A. Harker's 'Bala Volcanic Series of Cænarvonshire,' being the Sedgwick Prize Essay for 1888. F. Rutley, *Q. J. G. S.* xxxv. (1879), p. 508. W. W. Watts, *op. cit.* xli. (1885), p. 532. A. G. vol. xlvii. (1891), Presidential Address, p. 117; 'Ancient Volcanoes of Great Britain,' chap. xiii.

graptidæ disappear from sight altogether. The only families that survive into the Llandovery rocks are those of the Diplograptidæ and Retiolitidæ, and these only in a very degenerate form." Yet it is remarkable that it was during Caradoc time that the Dicranograptidæ and Leptograptidæ attained their highest development.[1]

To the conditions that allowed the deposition of limestone bands in this group we doubtless owe the presence of upwards of 40 species of corals belonging to *Alveolites*,

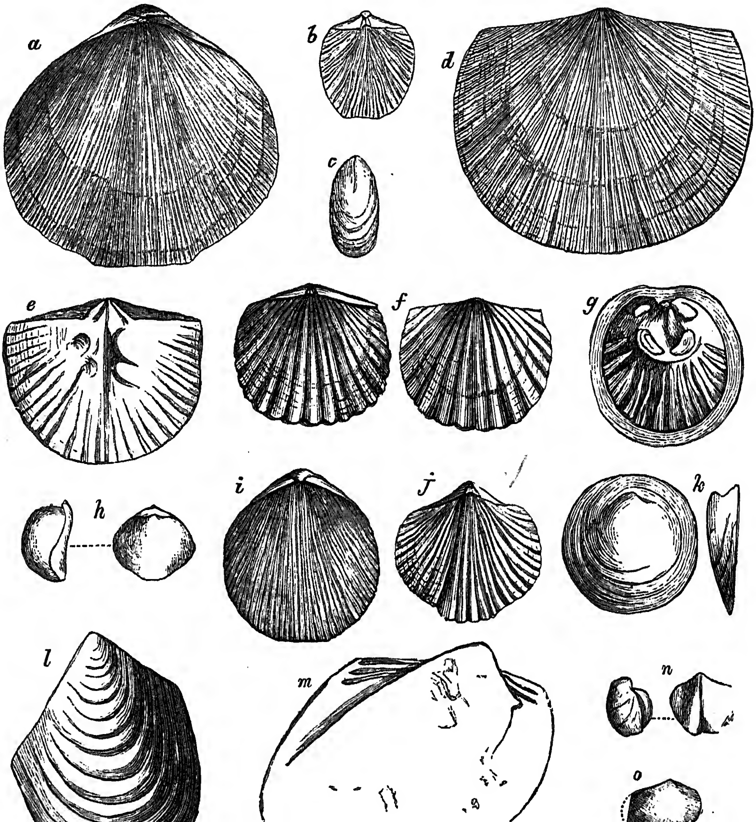

Fig. 379.—Group of Caradoc Fossils.

a, Porambonites intercedens, Pander; *b*, Orthis hirnantensis, McCoy; *c*, Lingula longissima, Pander (?) *d*, Strophomena grandis, Sby.; *e*, Orthis plicata, Sby; *f*, Orthis calligramma, Dalm.; *g*, Crania divaricata, McCoy; *h*, Triplesia (?) maccoyana, Dav.; *i*, Atrypa (?) Headii, Billings (?); *j*, Atrypa marginalis, Dalm.; *k*, Discina oblongata, Portl.; *l*, Ambonychia prisca, Portl.; *m*, Palæarca billingsiana, Salt.; *n*, Rhynchonella nana, Salt; *o*, Cleidophorus ovalis, McCoy.

Cyathophyllum, *Favosites*, *Halysites*, *Heliolites*, *Monticulipora*, &c. The echinoderms are represented by crinoids of the genera *Cyathocrinus* and *Glyptocrinus*; by numerous species of cystideans (*Echinosphærites*, *Sphæronites*, *Agelacrinites*, *Hemicosmites*, &c.); by brittle-stars (*Protaster*), and by star-fishes of the genera *Palæaster* and *Stenaster*; the

[1] Lapworth, *Ann. Mag. Nat. Hist.* v. (1880), p. 358 *seq.*

annelids by *Serpulites*, and numerous burrows and tracks; the trilobites by species of *Acidaspis*, *Ampyx*, *Asaphus*, *Calymene*, *Cheirurus*, *Cybele*, *Encrinurus*, *Homalonotus*, *Illænus*, *Lichas*, *Phacops*, *Remopleurides*, *Trinucleus;* the ostracods by *Beyrichia*, *Leperditia*, *Cythere*, *Primitia*, and *Entomis;* the polyzoa by *Fenestella*, *Glauconome*, *Ptilodictya*, and *Phyllopora;* the brachiopods by *Atrypa*, *Meristella*, *Leptæna*, *Orthis*, *Plectambonites*, *Strophomena*, *Crania*, *Trematis* (*Discina*), and *Lingula;* the lamellibranchs by *Ctenodonta*, *Orthonota*, *Modiolopsis*, *Pterinea*, *Ambonychia*, *Palæarca;* the gasteropods by *Murchisonia*, *Pleurotomaria*, *Raphistoma*, *Cyclonema*, *Cyrtolites*, *Holopæa*, *Holopella*, *Bellerophon*, *Ecculiomphalus*, and *Maclurea;* the pteropods by *Tentaculites*, *Conularia*, and *Hyolithes;* and the cephalopods by the genera *Orthoceras*, *Cyrtoceras*, *Trocholites* (*Lituites*), &c.

The Lower Silurian rocks, typically developed in Wales, extend over much of Britain, though largely buried under more recent formations. They rise into the hilly tracts of Westmoreland and Cumberland,[1] where they consist of the following subdivisions in descending order:—

Coniston Limestone series with the Ashgill shales above the limestone and the Dufton shales below it	=	Bala beds.
Borrowdale volcanic series (green slates and porphyries): tuffs and lavas without ordinary sedimentary strata except at base, 12,000 ft.	=	Part of Bala, whole of Llandeilo, and perhaps part of Arenig groups.
Skiddaw Slates, 10,000 or 12,000 ft., base not seen	=	Arenig group, with perhaps Tremadoc Slates and Lingula Flags.

Apart from the massive intercalation of volcanic rocks, these strata present considerable lithological and palæontological differences from the typical subdivisions in Wales. The Skiddaw slates are black or dark-grey, argillaceous, and in some beds sandy rocks, often much cleaved, though seldom yielding workable slates, sometimes soft and black, like Carboniferous shale. As a rule, they are singularly unfossiliferous, but in some of their less cleaved and altered portions, they have yielded *Lingula brevis*, traces of annelids, a few trilobites (*Æglina*, *Agnostus*, *Asaphus*, &c.), some phyllocarids (*Caryocaris*), and remains of plants (?) (*Bythotrephis*, &c.). But their most abundant and characteristic fossils are graptolites, of which 59 species have been determined. These organisms indicate that, while the main mass of the slates may be regarded as of Arenig age, the lowest parts of the series, where *Bryograptus* and *Clonograptus tenellus* are found, probably belong to the Tremadoc group; the highest portions, containing *Diplograptus*, *Didymograptus*, *Placoparia*, &c. appear to represent the lower part of the Llandeilo (Llanvirn) series of Wales. Of the whole of this graptolitic fauna 14 species are found in other parts of Britain, 25 occur in the Quebec group of Canada, and no fewer than 34 are common to the Skiddaw slates and to the Lower Silurian series of Sweden.[2] These slates, as already mentioned (p. 779), have been invaded by granite and other eruptive rocks, and have undergone marked contact-metamorphism.

Towards the close of the long period represented by the Skiddaw slates, volcanic action manifested itself, first by intermittent showers of ashes and streams of lava, which were interstratified with the ordinary marine sediment, and then by a more powerful and continuous series of explosions, whereby a huge volcanic mountain or group of cones was piled up above the sea-level. The vast pile of volcanic material (estimated at some 12,000 feet in total thickness) consists entirely of lavas and ashes without the interstrati

[1] Sedgwick's 'Three Letters addressed to W. Wordsworth,' 1843. J. C. Ward, "Geology of the North Part of the English Lake District" (*Geological Survey Memoir*), 1876. Nicholson, 'Essay on the Geology of Cumberland and Westmoreland,' 1868. See also papers by Harkness, Nicholson, Hughes, Marr, and others in *Q. J. G. S.* and *Geol. Mag.*

[2] Miss G. L. Elles, *Q. J. G. S.* liv. (1898), p. 525. See also Mr. J. Marr, *Geol. Mag.* 1894, p. 122.

fication of ordinary sediment except at the base and the top. The lower lavas are varieties of andesite, which are also met with in the central and higher parts of the Borrowdale volcanic series, while rhyolitic felsites were specially poured out towards the close of the volcanic period. Enormous quantities of fine volcanic ashes were likewise discharged. These various volcanic rocks form the picturesque hills of the Lake District.[1] The length of time occupied by this volcanic episode in Cumbrian geology may be inferred from the fact that all the Llandeilo and a large part of the Bala beds are absent here. The volcanic island slowly sank into a sea wherein Bala organisms flourished. In some places a group of shales occasionally 300 feet thick, and known as the Dufton shales, overlies the Borrowdale series, and contains among other characteristic species *Strophomena expansa*, *Plectambonites* (*Leptæna*) *sericea*, *Trinucleus concentricus*, *Homalonotus bisulcatus*, *Illænus Bowmanni*. The most marked rock of the overlying series is the Coniston limestone,[2] which has yielded such familiar Bala species as *Monticulipora* (*Favosites*) *fibrosa*, *Heliolites interstinctus*, *Cybele verrucosa*, *Plectambonites* (*Leptæna*) *sericea*, *Orthis Actoniæ*, *O. biforata*, *O. calligramma*, *O. elegantula*, *O. porcata*, and *Leptæna* (*Strophomena*) *rhomboidalis*. These organisms and their associates, gathering on the submerged flanks of the sinking volcano, before the eruptions had finally ceased, formed there the limestone now traceable for many miles through the Westmoreland hills, like the Bala limestone of North Wales, which, as already stated, it probably represents. The Coniston limestone is overlain by a conformable group of argillaceous strata (Ashgill shales) containing *Trinucleus concentricus*, *Phacops apiculatus*, *P. mucronatus*, *Strophomena siluriana*, and other Lower Silurian fossils. Not far to the east, at the base of the great Pennine escarpment, contemporaneous volcanic rocks in the Coniston series are well developed.[3] But the enormous volcanic group of Westmoreland and Cumberland dies out rapidly in that direction, for in the Craven district it is represented by a series of sandstones, grits, and slates (often green), probably 10,000 feet thick, which passes up conformably into the Coniston limestone series.[4] The most interesting feature of the Crossfell inlier is the occurrence of an isolated mass of limestone at Keisley, which has yielded a large and peculiar assemblage of fossils, that show it to belong to the base of the Upper Bala or Caradoc rocks, and to represent in a more complete form a zone which is elsewhere absent or only feebly developed in Britain. Among these organisms trilobites are specially prominent, no fewer than 17 genera and 43 species having been obtained. *Illænus*, *Cheirurus*, *Lichas* and *Harpes* are each represented by a number of species. The brachiopods are likewise numerous, particularly species of *Orthis*, *Rafinesquina*, *Plectambonites* and *Atrypa*, and the corals include *Halysites catenularia*, *Monticulipora fibrosa*, *Favosites alveolaris*, and *Streptelasma europæum*.[5]

The Southern Uplands of **Scotland** are formed almost wholly of Lower and Upper Silurian strata which have been thrown into innumerable plications, often overthrust and reversed. The unravelling of this complicated structure has been made possible chiefly by the evidence from certain zones of graptolitic shales, so well worked out by Professor Lapworth, and the whole region has since been mapped in detail and described by Messrs. Peach and Horne, of the Geological Survey.[6] The Arenig division

[1] On the volcanic geology of this region consult J. C. Ward in the work above cited. A. G., Presid. Address, *Q. J. G. S.* 1891, p. 137; 'Ancient Volcanoes of Great Britain,' vol. i., and authors there given. Also W. M. Hutchings, *Geol. Mag.* 1892, pp. 154, 218.

[2] On this limestone see Marr, *Geol. Mag.* 1892, pp. 97, 443.

[3] Harkness, *Q. J. G. S.* xxi. (1865), p. 235. Nicholson, *Geol. Mag.* 1869, p. 213. This "Crossfell inlier" has been described by Messrs. Nicholson, Marr, and Harker, *Q. J. G. S.* xlvii. (1891), p. 500.

[4] Hughes, *Geol. Mag.* iv. (1867), p. 346. This area had previously been described by Sedgwick, *Trans. Geol. Soc.* (2) iii. p. 1; and by Phillips, *Q. J. G. S.* viii. p. 35.

[5] F. R. Cowper Reed, *Q. J. G. S.* lii. (1896), p. 407; and liii. (1897), p. 67.

[6] Lapworth, in the papers cited on p. 965. B. N. Peach and J. Horne, "The Silurian

is represented by cherts containing radiolaria, mudstones, and grey shales, which in the central and northern parts of the region are associated with fine volcanic tuffs. In Ayrshire and the south-western districts, where the volcanic constituents attain a great development, they consist of basic lavas (diabase, &c.), with intercalated tuffs and agglomerates. A characteristic feature of these lavas is the development of ellipsoidal or pillow-structure in them (pp. 136, 306). This volcanic platform appears to underlie the Silurian region over an area of at least 2000 square miles, inasmuch as it comes to the surface wherever the crests of the anticlines bring up sufficiently deep parts of the formations. It is thus one of the most extensive as well as one of the most ancient volcanic tracts in Europe. The fossils include *Tetragraptus* (6 species), *Dichograptus* (4), *Didymograptus* (4), *Trigonograptus* (1), *Phyllograptus* (1), *Dendrograptus* (1), *Climacograptus* (1), and *Dictyonema* (1); *Caryocaris Wrightii*, *Acrothele* (2 species), *Acrotreta* (2), *Kutorgina* (2), *Lingula* (1), *Lingulella* (3); *Linnarssonia* (2), *Obolella* (3), with the glass-rope sponge *Hyalostelia* and annelid jaws referred to *Arabellites*.

The Llandeilo division is generally represented in the lower part by radiolarian cherts and mudstones, which immediately overlie the Arenig rocks; in the upper part by greywackes and shales, including the Glenkiln Black Shales, bands of red nodular chert, with courses of red and green mudstone, fine volcanic tuffs, massive grey and black cherts and occasional black shales containing Upper Llandeilo graptolites—*Stephanograptus* (*Cœnograptus*) *gracilis*, the zonal form, with *Didymograptus* (2 species), *Thamnograptus* (2), *Clathrograptus* (1), *Dicranograptus* (7), *Dicellograptus* (6), *Leptograptus* (1), *Diplograptus* (6), *Cryptograptus* (1), *Glossograptus* (1), *Lasiograptus* (2), *Climacograptus* (3), *Corynoides* (2), *Acrotreta*, *Acrothele*, *Siphonotreta*, *Discina*, *Hyalostelia*, and 22 species of radiolaria which abound in some of the bands of chert. In the Girvan district of Ayrshire, where a portion of the Llandeilo formation is absent and the remaining part lies unconformably on the Arenig cherts, massive conglomerates appear together with a thick limestone (Stinchar) and graptolitic mudstones. The limestone has yielded a large assemblage of fossils, conspicuous among which are nodules of *Girvanella* (probably related to the calcareous algæ), abundant corals, of which no fewer than 17 genera have been detected; numerous articulate brachiopods (*Leptæna*, 9 species; *Strophomena*, 9; *Rhynchonella*, 11; *Orthis*, 15; together with a few lamellibranchs, some gasteropods (*Maclurea*, *Ophileta*, *Murchisonia*, *Pleurotomaria*), and species of the cephalopods *Orthoceras*, *Cyrtoceras*, and *Trocholites*.

The Caradoc division in the central part of the region is represented by an upper group of green and grey mudstones with black shales, forming the Upper Hartfell Shales, and divided into an upper zone of *Dicellograptus anceps*, *Diplograptus truncatus*, and *Climacograptus scalaris*, a middle band of mudstone (unfossiliferous "Barren Mudstone") and a lower zone of *Dicellograptus complanatus*, and *Dictyonema moffatensis*. The lower group consists of a band of black shales about 50 feet thick, forming the Lower Hartfell Shales and containing the following zones in descending order: at the top, the zone of *Pleurograptus linearis*, with *Leptograptus flaccidus*, *Diplograptus foliaceus*, *Climacograptus tubuliferus*; in the centre, the zone of *Dicranograptus Clingani*, with *D. ramosus*, *Climacograptus caudatus*, *C. bicornis*, *Dicellograptus Forchhammeri*; at the bottom, the zone of *Climacograptus Wilsoni*, with *Cryptograptus tricornis*, *Diplograptus rugosus*, *Lasiograptus Harknessi*, *Climacograptus Schärenbergi*. In Ayrshire the Caradoc strata present themselves in a wholly different condition. They are much thicker and more varied in their lithological character, and they comprise a much more diversified fauna, but among the fossils the distinctive graptolites occur which serve to show the parallelism of these strata with the much thinner series of the Moffat region.

Reference has already been made (p. 797) to the occurrence of a belt of what appear to be rocks of Arenig age, wedged in along the border of the Scottish Highlands. These

Rocks of Britain: I. Scotland," in *Mem. Geol. Surv.* 1899,—a detailed monograph on the geology, petrography, and palæontology of the whole region.

rocks consist of radiolarian cherts or jaspers and slates, associated with basic ellipsoidal lavas (diabase). They present so close a resemblance to the Arenig band of similar rocks in the Southern Uplands as to afford strong reason to regard them as probably also of Arenig age. The radiolaria are not, however, sufficiently well preserved to admit of satisfactory comparison with those of the Arenig and Llandeilo cherts already referred to. This band of rocks has been traced along the margin of the Highland schists across Scotland into the island of Arran. It appears to be prolonged into Ireland and to expand there into a broad tract in county Tyrone. It is associated in Kincardineshire with a younger group of argillaceous and calcareous strata ("Margie series"). There can be no doubt that these rocks have suffered from the latest plication of the region, and they suggest that possibly some part of the Central Highlands may consist of altered Silurian sediments and igneous rocks, as we know that in the north-west both Cambrian and pre-Cambrian sedimentary materials have gone to the construction of the crystalline schists of that region.[1]

In the north-east of Ireland a broad belt of Silurian rocks, crossing from the south-west of Scotland, runs from the coast of Down into the heart of the counties of Roscommon and Longford. It is marked by the same graptolitic zones that occur in Scotland. The Glenkiln shales with their typical Llandeilo graptolites are found to the south of Belfast Lough, while the Hartfell shales with their Caradoc fossils have also been observed.[2] The richest fossiliferous localities among the Irish Silurian rocks are found at the Chair of Kildare,[3] Portrane near Dublin, Pomeroy in Tyrone, and Lisbellan in Fermanagh, where small protrusions of the older rocks rise as oases among the surrounding later formations. Portlock brought the northern and western localities to light, and Murchison pointed out that, while a number of the trilobites (*Trinucleus, Phacops, Calymene, Illænus*), as well as the simple plated Orthidæ, Leptænæ, and Strophomenæ, some spiral shells, and many Orthocerata, are specifically identical with those from the typical Caradoc and Bala beds of Shropshire and Wales, yet they are associated with peculiar forms, first discovered in Ireland, and very rare elsewhere in the British Islands. Among these distinctive fossils he cited the trilobites, *Remopleurides, Harpes, Amphion,* and *Bronteus,* with smooth forms of *Asaphus* (*Isotelus*), which, though abundant in Ireland and America, had seldom been found in Wales or England, and never on the continent.[4] To the north of the broad Silurian belt which crosses the island lies the tract in Tyrone, above referred to, where a remarkable series of cherts and jaspers like those of the Arenig group in the south of Scotland, is associated with a great development of ellipsoidal lavas, tuffs, and agglomerates, together with shales, grits, and limestones like those of the "Margie Series" of Kincardineshire. In the south-east of Ireland a large tract of Lower Silurian rocks extends through the counties of Wicklow, Wexford, and Waterford. In this area also the Llandeilo and Caradoc graptolitic zones occur. Even as far south as the southern coast-line of Waterford black shales continue the physical aspect of the Glenkiln shales, and contain some of the same graptolites.[5] We have thus evidence that the black carbonaceous mud in

[1] *Annual Reports of Geol. Survey* for 1893, 1895, and 1896; *Summary of Progress of Geol. Surv.* for 1899, p. 67. 'Ancient Volcanoes of Britain,' vol. i. p. 240. G. Barrow, *Q. J. G. S.* lvii. (1901), p. 328.

[2] W. Swanston, *Trans. Belfast Nat. Field Club,* 1876-77. Lapworth, *Ann. Mag. Nat. Hist.* iv. (1879), p. 424.

[3] See the recent detailed account of this locality by Messrs. Reynolds and Gardiner, *Q. J. G. S.* lii. (1896), p. 587. The same geologists have also subsequently studied the Portrane inlier (*op cit.* liii. 1897, p. 520); and Lambay Island (liv. 1898, p. 135). The Balbriggan district has been described by W. Andrews, *Geol. Mag.* 1899, p. 395.

[4] 'Siluria,' p. 174. The upper portion of the Pomeroy section has yielded Llandovery graptolites, so that the strata there are partly Lower and partly Upper Silurian.

[5] The geology of the Waterford coast was described by Jukes and Du Noyer in the

which these graptolites lived spread over the sea-floor for a distance of at least 300 miles.

Upper Silurian.—Wales and Shropshire.—This series of rocks occurs in two very distinct lithological types in the British Islands. So great indeed is the contrast between these types, that it is only by a comparison of organic remains that the whole has been grouped together as the deposits of one geological period. In the original Shropshire region described by Murchison, and from which his type of the system was taken, the strata are comparatively flat, soft, and unaltered, consisting mainly of somewhat incoherent sandy mudstone and shale, with occasional bands of limestone. But as these rocks are followed into North Wales, they are found to pass into a thick series of grits and shales, so like portions of the hard altered Lower Silurian rocks that, save for the evidence of fossils, they would naturally be grouped as part of that more ancient series. In Westmoreland and Cumberland, and still farther north in the border counties of Scotland, also in the south-west of Ireland, it is the North Welsh type which prevails. This type, therefore, is really the prevalent one in Britain, extending over many hundreds of square miles, while the original Shropshire type hardly spreads beyond the border district between England and Wales.

Taking first the original tract of Siluria (W. England and E. and S.E. Wales), we find a decided unconformability separating the Lower from the Upper Silurian deposits. In some places the latter steal across the edges of the former, group after group, till they lie directly upon the Cambrian rocks. Indeed, in one district, between the Longmynd and Wenlock Edge, the base of the Upper Silurian rocks is found within a few miles to pass from the Caradoc group across to the Longmyndian rocks. It is evident, therefore, that in that region very great disturbance and extensive denudation preceded the commencement of the deposition of the Upper Silurian rocks. As Ramsay pointed out, the area of Wales, previously covered by a wide though shallow sea, was ridged up into a series of islands, round the margin of which the conglomerates at the base of the Upper Silurian series began to be laid down. This took place during a time of submergence, for these conglomeratic and sandy strata are found creeping up the slopes and even capping some of the hills, as at Bogmine, where they reach a height of 1150 feet above the sea. The subsidence probably continued during the whole of the interval occupied by the deposition of the Upper Silurian strata, which were thus piled to a depth of from 3000 to 5000 feet over the disturbed and denuded platform of Lower Silurian rocks.

Arranged in tabular form, the subdivisions of the Upper Silurian rocks of Wales and the adjoining counties of England are in descending order as follows :—

	Base of Old Red Sandstone.
3. Ludlow group.	Tilestones. Downton Castle Sandstone, 90 feet. Ledbury Shales, 270 feet. Upper Ludlow Rock, 140 feet. Aymestry Limestone, up to 30 or 40 feet. Lower Ludlow Rock, 350 to 780 feet.
2. Wenlock group.	Wenlock or Dudley Limestone, 90 to 300 feet. Wenlock Shale, up to 1900 feet. Woolhope or Barr Limestone and Shale, 150 feet.
1. Llandovery group.	Tarannon Shales, 1000 to 1500 feet. Upper Llandovery Rocks and May Hill Sandstone, 800 feet. Lower Llandovery Rocks, 600 to 1500 feet.

1. Llandovery Group.—The most marked lithological character of this group in Britain is the occurrence of conglomerates which indicate the terrestrial disturbance

Geological Survey Memoir on Sheets 167, 168, 178, and 179 (1865), Ireland. A. G., 'Ancient Volcanoes of Great Britain,' vol. i. The ground has recently been studied by Mr. F. R. C. Reed, *Q. J. G. S.* lv. (1899), p. 718; lvi. (1900), p. 657; *Geol. Mag.* 1897, p. 520.

and extensive denudation that followed the close of the deposition of the Lower Silurian rocks.

(*a*) *Lower Llandovery.*—In North Wales, the Bala beds, about five miles S.E. of Bala Lake, begin to be covered with grey grits, which gradually expand southwards until in the Rhayader district of Radnorshire they attain a thickness of 1830 feet. These overlying rocks are well displayed near the town of Llandovery, where they contain some conglomerate bands, and where Mr. Aveline detected an unconformability between them and the Bala group below them. Elsewhere they seem to graduate downwards conformably into that group. They cover a considerable breadth of country in Cardigan and Carmarthenshire, owing to the numerous undulations into which they have been thrown, and they extend as far as Haverford West in Pembrokeshire. A marked change is now visible in the fossil contents of the rocks, as compared with those of the Lower Silurian subdivisions. Thus the familiar Lower Silurian types of trilobites become few or extinct, such as *Agnostus*, *Ampyx*, *Asaphus*, *Ogygia*, *Remopleurides*, *Trinucleus*, and their places are taken in Upper Silurian formations by species of *Acidaspis*, *Encrinurus*, *Phacops*, *Proëtus*, and other genera. A still more striking contrast occurs among the types of graptolites. The families of the Dicranograptidæ, Leptograptidæ, and Lasiograptidæ wholly disappear, and the forms which now take their place and distinguish the Upper Silurian rocks belong to the Monograptidæ, which gradually exclude the Diplograptidæ, until before the higher parts of the system are reached they are the sole representatives of the graptolites. Three graptolitic zones have been recognised in the Lower Llandovery group, viz. in ascending order: (1) *Diplograptus acuminatus*, (2) *Diplograptus vesiculosus*, (3) *Monograptus gregarius*. Besides these species, *Monograptus tenuis*, *M. attenuatus*, *M. crenularis*, *M. lobiferus*, *Climacograptus undulatus*, *C. normalis* and *C. rectangularis* are common Lower Llandovery forms. Other characteristic fossils are *Orthis elegantula*, *O. testudinaria*, *Stricklandinia* (*Pentamerus*) *lens*, and *Meristella crassa*. From the abundance of the peculiar brachiopods termed *Pentamerus* in the Lower, but still more in the Upper Llandovery rocks, these strata were formerly grouped together under the name of "Pentamerus beds" (Fig. 380). Though the same species are found in both divisions, *Pentamerus oblongus* is chiefly characteristic of the upper group and comparatively infrequent in the lower, while *Stricklandia* (*Pentamerus*) *lens* abounds in the lower, but appears more sparingly in the upper. The genus ascends into the Wenlock and Ludlow groups, and is specially distinctive of Upper Silurian rocks.[1]

(*b*) *Upper Llandovery and May Hill Sandstone.*—This sub-group has received the name of May Hill Sandstone from the locality in Gloucestershire where, as first shown by Murchison, it is well displayed. Sedgwick pointed out that it forms over a wide region the natural base to the Upper Silurian series, for it rests unconformably on all older rocks. It consists of grey, yellow, and brown ferruginous sandstones and conglomerates, sometimes calcareous from the abundance of shells, which are apt to weather out and leave casts. Where the organisms have been most crowded together the rock even passes into a limestone (Pentamerus limestone, Norbury Limestone, Hollies Limestone). The lower members are usually strongly conglomeratic, the pebbles being derived, sometimes in great part, from Lower Silurian rocks. Appearing on the coast of Pembrokeshire at Marloes Bay, this sub-group ranges across South Wales until it is overlapped by the Old Red Sandstone. It emerges again in Carmarthenshire, and trends north-eastward as a narrow strip at the base of the Upper Silurian series, from a few feet to 1000 feet or more in thickness, as far as the Longmynd, where, as a marked conglomerate wrapping round that ancient ridge, it disappears. In the course

[1] The Lower and Upper Llandovery rocks of Central Wales have recently been the subject of an exhaustive stratigraphical and palæontological study by Mr. H. Lapworth, who has unravelled their succession and recognised among them their characteristic graptolitic zones, *Q. J. G. S.* lvi. (1900), pp. 67-135.

of this long tract it passes successively and unconformably over Lower Llandovery, Caradoc, Llandeilo, Cambrian, and pre-Cambrian rocks.[1]

Among the fossils are traces of fucoids and sponges; numerous graptolites (*Monograptus Sedgwickii, M. Clingani, M. spiralis, M. convolutus, M. Proteus, M. lobiferus, Climacograptus normalis, Diplograptus Hughesii, D. sinuatus, Dictyonema corrugatellum, D. delicatulum, Calyptograptus digitatus, Retiolites perlatus*); a number of corals (*Lindostræmia, Heliolites, Favosites, Halysites, Syringopora*, &c.); a few crinoids and sea-urchins (*Palæechinus*); the pteropod *Tentaculites* (particularly abundant); a number of trilobites, of which *Phacops caudatus, P. Stokesii, P. Weaveri, Encrinurus punctatus, Calymene Blumenbachii, Proëtus Stokesii*, and *Illænus Thomsoni* are common; numerous brachiopods, as *Atrypa hemispherica, A. reticularis, Pentamerus oblongus, Stricklandinia lirata, S. lens, Plectambonites transversalis, Orthis calligramma, O. elegantula, O. reversa, Strophomena compressa, S.* (*Orthothetes*) *pecten*, and *Lingula parallela;* lamellibranchs of the mytiloid genera *Orthonota* and *Modiolopsis*, with forms of *Pterinea, Ctenodonta*, and *Lyrodesma*; gasteropods, particularly the genera *Raphistoma, Murchisonia, Pleurotomaria, Cyclonema, Holopella*, and the species *Bellerophon dilatatus, B. trilobatus*, and *B. carinatus;* and cephalopods, chiefly *Orthoceras*, with some forms of *Actinoceras, Cyrtoceras, Tretoceras*, and *Phragmoceras*, and the old species *Trochoceras* (*Lituites*) *cornu-arietis*.

(*c*) *Tarannon Shale.*—Above the Upper Llandovery beds comes a very persistent band of fine, smooth, light grey or blue slates, which has been traced from the mouth of the Conway into Carmarthenshire. These strata, termed the "paste-rock" by Sedgwick, have an extreme thickness of 1000 to 1500 feet. Poor in organic remains, their chief interest lies in the fact that the persistence of so thick a band of rock between what were supposed to be continuous and conformable formations should have been unrecognised until it was proved by the detailed mapping of the Geological Survey. The occurrence of certain species of graptolites affords a palæontological basis for placing on this horizon a considerable mass of slaty and gritty strata in Cardiganshire, and for identifying these and the typical Tarannon Shales with their probable equivalents in the Lake District and in Scotland. The following graptolitic zones in ascending order have been determined in the Tarannon rocks: (1) *Rastrites maximus*, (2) *Monograptus exiguus*, (3) *Cyrtograptus Grayæ*. From the "Pale Shales" of Rhayader, which lie on the same horizon as the Tarannon Shales, Mr. H. Lapworth has obtained a large number of graptolites, including *Monograptus exiguus, M. discus, M. nudus, M. priodon, M. Becki, M. crassus, M. jaculum, M. pandus, M. involutus, M. Sedgwickii, M. lobiferus, Retiolites obesus, Rastrites distans, Petalograptus palmeus.*

2. Wenlock Group.—This suite of strata includes the larger part of the known Upper Silurian fauna of Britain, as it has yielded more than 160 genera and 500 species. In the typical Silurian area of Murchison, it consists of two limestone bands (Woolhope and Wenlock), separated by a thick mass of shale (Wenlock Shale). The following sub-groups in ascending order are recognised:—

(*a*) *Woolhope Limestone.*—In the original typical Upper Silurian tract of Shropshire and the adjacent counties, the Upper Llandovery rocks are overlain by a local group of grey shales, containing nodular limestone which here and there swells out into beds having an aggregate thickness of 30 or 40, but at Malvern as much as 150 feet. These strata are well displayed in the picturesque valley of Woolhope in Herefordshire, which lies upon a worn quâ-quâ-versal dome of Upper Silurian strata, rising in the midst of the surrounding Old Red Sandstone. They are seen likewise to the north-west, at Presteign, Nash Scar, and Old Radnor in Radnorshire, and to the east and south, in the Malvern Hills (where they include a great thickness of shale below the limestone), and

[1] For a recent account of the Llandovery rocks and fossils of the Conway district see Misses G. L. Elles and E. M. R. Wood, *Q. J. G. S.* lii. (1896), p. 273. These rocks in the Rhayader district have been admirably worked out by Mr. H. Lapworth in the paper above cited.

May Hill in Gloucestershire. Among the common fossils of these strata may be mentioned *Illænus* (*Bumastus*) *barriensis*, *Homalonotus delphinocephalus*, *Phacops caudatus*, *Encrinurus punctatus*, *Acidaspis Brightii*, *Atrypa reticularis*, *Orthis calligramma*, *Strophomena* (*Stropheodonta*) *imbrex*, *S.* (*Strophonella*) *euglypha*, *Plectambonites transversalis*, *Rhynchonella* (*Camarotœchia?*) *borealis*, *R.* (*Wilsonia*) *Wilsoni*, *Omphalotrochus* (*Euomphalus*) *sculptus*, *Orthoceras annulatum*.

It is a feature of the older Palæozoic limestones to occur in a very lenticular form, swelling in some places to a great thickness and rapidly dying out, to reappear again perhaps some miles away with increased proportions. This local character is well

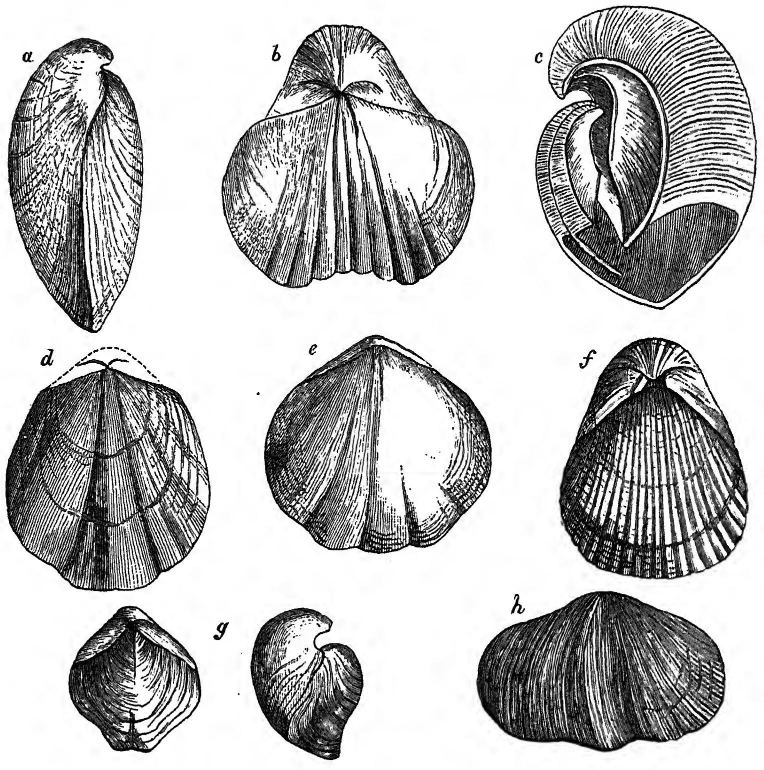

Fig. 380.—Group of Pentameri from Llandovery and Wenlock Rocks.
a, Pentamerus oblongus, Sby.; *b*, P. galeatus, Dalm.; *c*, P. Knightii, Sby.; *d*, P. oblongus, Sby.; *e*, P. rotundus, Sby. (?); *f*, P. Knightii (small specimen); *g*, P. linguifer, Sby.; *h*, P. undatus, Sby.

exhibited by the Woolhope limestone. Where it disappears, the shales underneath and intercalated with it join on continuously to the overlying Wenlock shale, and no line for the Woolhope sub-group can then be satisfactorily drawn. The same discontinuity is strikingly traceable in the Wenlock limestone to be immediately referred to.

(*b*) *Wenlock Shale.*—This sub-group consists of grey and black shales, traceable from the banks of the Severn near Coalbrook Dale across Radnorshire to near Carmarthen—a distance of about 90 miles. The same strata reappear in the protrusions of Upper Silurian rocks which rise out of the Old Red Sandstone plains of Gloucestershire, Herefordshire, and Monmouthshire. In the Malvern Hills, they were estimated by

Professor Phillips to reach a thickness of 640 feet, but towards the north they thicken out to nearly 2000 feet. On the whole, the fossils are identical with those of the overlying limestone. The corals, however, so abundant in that rock, are here comparatively rare. The brachiopods (*Lingula*, *Leptæna*, *Orthis*, *Strophomena*, *Atrypa*, *Rhynchonella*, *Spirifer*) are generally of small size—*Orthis biloba*, *O. hybrida*, and the large flat *O. rustica* being characteristic.[1] Of the higher mollusca, thin-shelled forms of *Orthoceras* are specially abundant. Among the trilobites, *Encrinurus punctatus*, *E. variolaris*, *Calymene Blumenbachii*, *C. tuberculosa*, *Phacops caudatus*, *P. longicaudatus* are common. Distinctive species of graptolites have long been known to characterise the shales of this group.[2] In 1882 Tullberg showed that the equivalent strata of the Wenlock shales in Scania could be divided into zones by means of their distinctive graptolites.[3] Miss Elles, after a study of the Swedish succession, has recently succeeded in applying the zonal classification, by means of graptolites, to the Wenlock shales along the borders of England and Wales.[4] She has traced six zones in the following order, beginning with the lowest :—1, zone of *Cyrtograptus Murchisoni*, containing besides, in great abundance, *Monograptus priodon*, *M. vomerinus*, *M. Hisingeri*, *Retiolites geinitzianus*; 2, zone of *Monograptus riccartonensis*, including also numerous specimens of *M. vomerinus*, *M. capillaceus*, *Cyrtograptus flaccidus*; 3, zone of *Cyrtograptus symmetricus*, with abundant *M. vomerinus*, *M. dubius*; 4, zone of *Cyrtograptus Linnarssoni*, with plenty of *M. vomerinus*, *M. dubius*, *M. flexilis*; 5, zone of *Cyrtograptus rigidus*, including also abundantly *M. vomerinus*, *M. dubius*, *M. retroflexus*, *M. Flemingii*; 6, zone of *Cyrtograptus Lundgreni*, with numerous *M. vomerinus*, *M. dubius*, *M. Flemingii*, *M. irfonensis*, and *Cyrtograptus Carruthersi*.

(*c*) *Wenlock Limestone.*—This is a thick-bedded, sometimes flaggy, usually more or less concretionary limestone, grey or pale pink, often highly crystalline, occurring in some places as a single massive bed, in others as two or more bands separated by grey shales, the whole forming a thickness of rock ranging from 100 to 300 feet.[5] As its name denotes, it is typically developed along Wenlock Edge in Shropshire, where it runs as a prominent ridge for fully 20 miles; also between Aymestry and Ludlow. It likewise appears at the detached areas of Upper Silurian strata above referred to, being specially well seen near Dudley (whence it is often spoken of as the Dudley limestone), Woolhope, Malvern, May Hill, and Usk in Monmouthshire.

A distinguishing characteristic of the Wenlock limestone is the abundance and variety of its corals, of which no fewer than 24 genera and upwards of 80 species have been described. The rock seems, indeed, to have been formed in part by massive sheets and bunches of coral. Characteristic species are *Halysites catenularia*, *Heliolites interstinctus*, *Propora tubulata*, *Alveolites Labechei*, *Favosites aspera*, *F. gotlandica*, *Cœnites juniperinus*, *Syringopora fascicularis*, *Omphyma subturbinatum*. The crinoids are also specially abundant, and often beautifully preserved, *Periechocrinus moniliformis* being one of the most frequent; others are *Crotalocrinus rugosus*, *Gissocrinus* (*Cyathocrinus*) *goniodactylus*, and *Marsipocrinus cælatus*. Several cystideans occur, of which one is *Lepadocrinus* (*Pseudocrinites*) *quadrifasciatus*. More than 30 species of annelids

[1] As an example of the small size but extraordinary abundance of brachiopods in this formation reference may be made to the fact that a cartload of the shale from Buildwas was found by careful washing to contain no fewer than 4300 specimens of one species (*Orthis biloba*), besides a much greater bulk of other brachiopods, amounting together to 10,000 specimens at least; while from seven tons weight of the shale at least 25,000 specimens of *Orthis biloba* were obtained.—Davidson and Maw, *Geol. Mag.* 1881, pp. 1, 100, 145, 289.

[2] Lapworth, *Ann. Mag. Nat. Hist.* v. (1880), p. 369.

[3] *Sverig. Geol. Undersökn*, C. No. 50, p. 15.

[4] *Q. J. G. S.* lvi. (1900), p. 370.

[5] On the microscopic structure of this limestone see Wethered, *Q. J. G. S.* xlix. (1893), p. 236.

have been found. The crustaceans include numerous trilobites, one of the most abundant being the long-lived *Calymene Blumenbachii*, which ranges from the Llandeilo flags (possibly from a still lower horizon) up to near the top of the Upper Silurian formations. It occurs abundantly at Dudley, where it received the name of the "Dudley Locust." Other common forms are *Encrinurus punctatus*, *E. variolaris*, *Phacops caudatus*, *P. Downingiæ*, *P. Stokesii*, *Illænus* (*Bumastus*) *barriensis*, *Homalonotus delphinocephalus* and *Cheirurus bimucronatus*. One of the most remarkable features in the arthropod fauna is the first appearance of the merostomata, which are represented by *Eurypterus punctatus*, *Hemiaspis horridus*, and perhaps *Pterygotus*. The brachiopods continue to be abundant, upwards of 20 genera and 100 species having been enumerated. Among typical species may be noted *Atrypa reticularis*, *Meristina tumida*, *Spirifer*

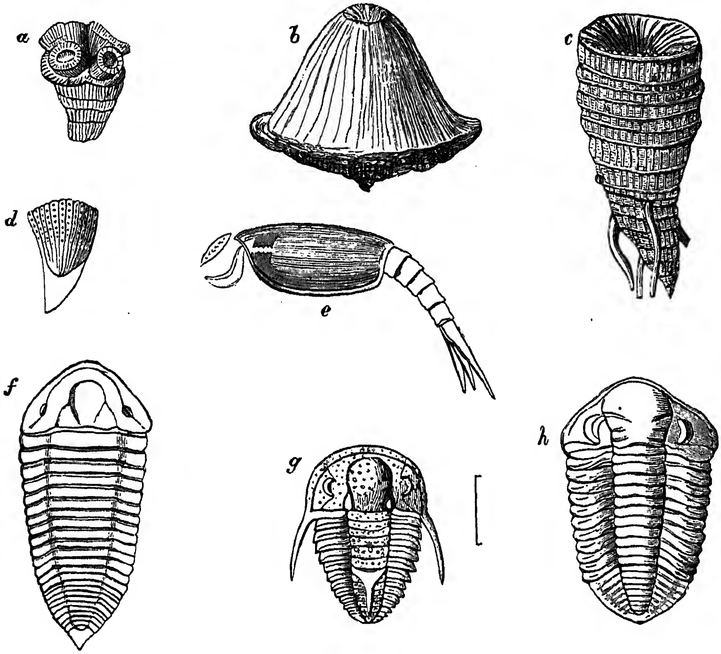

Fig. 381.—Upper Silurian Corals and Crustaceans.

a, Acervularia ananas, Linn.; *b*, Ptychophyllum patellatum, Schloth. (½); *c*, Omphyma subturbinatum, Linn. (½); *d*, Petraia bina, Lons.; *e*, Ceratiocaris papilio, Salt. (½); *f*, Homalonotus delphinocephalus, Green (¼); *g*, Cyphaspis megalops, McCoy; *h*, Phacops Downingiæ, Murch.

elevatus, *S. plicatellus*, *Rhynchonella* (*Camarotœchia?*) *borealis* (very common), *R.* (*Rhynchotreta*) *cuneata*, *R.* (*Wilsonia*) *Wilsoni*, *Orthis elegantula*, *O. hybrida*, *Leptæna rhomboidalis*, and *Pentamerus galeatus*. The lamellibranchs are abundant and are represented by species of *Avicula*, *Pterinea*, *Cardiola* and *Cucullella*, with *Grammysia cingulata*, *Orthonota amygdalina*, and some species of *Modiolopsis* and *Ctenodonta*. The gasteropods are marked by species of *Omphalotrochus*, *Murchisonia*, *Cyclonema*, *Platyceras*, and the common and characteristic *Bellerophon wenlockensis*. The cephalopods are represented by *Trochoceras*, *Cyrtoceras*, *Orthoceras*, and *Phragmoceras*; of these the orthoceratites are by far the most abundant both in species and individuals, *Orthoceras annulatum* being the most common form. The beautiful and abundant *Conularia Sowerbyi* is a characteristic organism of this group.

3. Ludlow Group.—This group consists essentially of shales, with occasionally a calcareous band in the middle. It graduates downward into the Wenlock group, so that when the Wenlock limestone disappears, the Wenlock and Ludlow shales form one continuous argillaceous formation, as they do where they stretch to the south-west through Brecon and Carmarthen. The Ludlow rocks, typically seen between Ludlow and Aymestry, appear likewise at the detached Silurian areas from Dudley to the mouth of the Severn. They were arranged by Murchison in three sub-groups—Lower Ludlow Rock, Aymestry Limestone, and Upper Ludlow Rock.

(*a*) *Lower Ludlow Rock.*—This sub-group consists of soft dark grey to pale greenish-brown or olive sandy shales, often with calcareous concretions. Much of the rock, however, presents so little fissile structure as to get the name of mudstone, weathering out into concretions which fall to angular fragments as the rock crumbles down. It becomes more sandy and flaggy towards the top. From the softness of the shales, this zone of rock has been extensively denuded, and the Wenlock limestone rises up boldly from under it. It attains a thickness of 780 feet at Ludlow. Abundantly fossiliferous, it is particularly rich in graptolites, which have a special interest as the last great assemblage of these organisms before their final extinction. They have been employed to mark off this sub-group of strata into zones, the most recent and exhaustive investigation in the subject having been made by Miss Wood, who has collected largely from the typical district and from the prolongation of the rocks along the Welsh border. She subdivides the Lower Ludlow shales in the Ludlow district into the following zones in ascending order :—1, zone of *Monograptus vulgaris*, consisting of thinly-bedded shales, 130 feet ; 2, zone of *M. Nilsoni*, 120 feet (*M. dubius, M. colonus, M. Roemeri, M. varians, M. chimæra, M. uncinatus*) ; 3, zone of *M. scanicus*, 100 feet (*M. dubius, M. Roemeri, M. varians, M. chimæra, M. bohemicus*) ; 4, zone of *M. tumescens*, 220 feet (*M. chimæra, M. bohemicus*) ; 5, zone of *M. leintwardinensis*, 210 feet.

Among the other fossils are the brittle-star *Protaster*, the star-fish *Palæocoma*, and the echinoid *Palæodiscus*. Of the corals, a few species survived from the time of the Wenlock Limestone, but the conditions of deposit were evidently unfavourable for their growth. The trilobites are less numerous than in older groups ; they include the venerable *Calymene Blumenbachii ;* also *Phacops caudatus, P. constrictus, P. Downingiæ, Acidaspis coronatus, Cheirurus bimucronatus, Encrinurus punctatus, Lichas anglicus, Homalonotus delphinocephalus, H. Knightii*, and *Cyphaspis megalops*. But other forms of arthropod life occur in some number. The phyllocarids are represented by species of *Ceratiocaris* and *Xiphocaris ;* the merostomata by species of *Eurypterus, Hemiaspis, Pterygotus.* Though brachiopods are not scarce, hardly any seem to be peculiar to the Lower Ludlow rock, nearly all of the known species occurring in the Wenlock group. *Rhynchonella* (*Wilsonia*) *Wilsoni, Cyrtia* (*Spirifer*) *exporrecta, Spirifer crispus, S. bijugosus, Strophomena* (*Strophonella*) *euglypha, Leptæna rhomboidalis, Rhynchonella* (*Camarotœchia*) *nucula, Atrypa reticularis, Orbiculoidea Morrisii, Lingula lata*, and *L. Lewisii* are not infrequent. Among the more commonly recurring species of lamellibranchs the following may be named—*Cardiola interrupta, Ambonychia* (*Cardiola?*) *striata, Ctenodonta sulcata, Grammysia cingulata, Modiolopsis gradata, M. Nilssoni, Orthonota amygdalina, O. rigida, O. semisulcata*, and a number of species of *Pterinea.* The gasteropods *Cyclonema corallii, Omphalotrochus* (*Euomphalus*) *alatus, Holopella gregaria, Loxonema sinuosa*, and *Murchisonia Lloydii* are frequent, and the old genus *Bellerophon* is still represented (*B. expansus*). Cephalopods abound, the genus *Orthoceras* being the prevalent type (*O. angulatum, O. annulatum, O. bullatum, O. ludense, O. subundulatum, O. tracheale*), but with species of *Trochoceras* and *Gomphoceras.* The numbers of straight and curved cephalopods form one of the distinguishing features of the zone. At one locality, near Leintwardine in Shropshire, which has been prolific in Lower Ludlow fossils, particularly in star-fishes and eurypterid crustaceans, a fragment of *Cyathaspis ludensis* was discovered in 1859. This is the earliest trace of vertebrate life yet detected in Britain.

(*b*) *Aymestry Limestone*—a dark grey, somewhat earthy, concretionary limestone in beds from 1 to 5 feet thick. Where at its thickest (from 30 to 50 feet) it forms a conspicuous feature, rising above the soft and denuded Lower Ludlow shales. Owing to the easily removable nature of some fullers'-earth on which it lies, it has here and there been dislocated by large landslips. It is still more inconstant than the Wenlock limestone. Though well developed at Aymestry in Herefordshire, it soon dies away into bands of calcareous nodules, which finally disappear, and the lower and upper divisions of the Ludlow group then come together. The organic remains at present known are for the most part identical with Wenlock forms. It is evident that the organisms which flourished so abundantly in the clear water wherein the Wenlock limestone was accumulated, continued to live outside the area of deposit of the Lower Ludlow rock, and reappeared in that area with the return of the conditions for their existence during the deposition of the Aymestry limestone. The most characteristic fossil of the latter rock is the *Pentamerus Knightii;* other common forms are *Rhynchonella* (*Wilsonia*) *Wilsoni*, *Dayia* (*Terebratula*) *navicula*, *Lingula Lewisii*, *Strophomena* (*Strophonella*) *euglypha*, *Atrypa reticularis*, *Pterinea Sowerbyi*, with many of the same shells, corals, and trilobites found in the Wenlock limestone. Indeed, as Murchison has pointed out, except in the less number of species and the occurrence of some of the shells more characteristic of the Upper Ludlow zone, there is not much palæontological distinction between the two limestones.[1]

(*c*) *Upper Ludlow Rock.*—In the original Silurian district described by Murchison, the Aymestry limestone is covered by a calcareous shelly band full of *Dayia* (*Rhynchonella*) *navicula*, sometimes 30 or 40 feet thick. This layer is succeeded by grey sandy shale or mudstone, often weathering into concretions, as in the Lower Ludlow zone, and assuming externally the same rusty-brown or greyish olive-green hue. Its harder beds are quarried for building stone; but the general character of the deposit, like that of the argillaceous portions of the Upper Silurian formations as a whole, in the typical district of Siluria, is soft, incoherent, and crumbling, easily decomposing once more into clay or mud, and presenting, in this respect, a contrast to the hard, fissile, and often slaty shales of the Lower Silurian series. Many of the sandstone beds are crowded with ripple-marks, rill-marks, and annelid-trails, indicative of the shallow littoral waters in which they were deposited. One of the uppermost sandstones is termed the "Fucoid Bed," from the number of its cylindrical seaweed-like stems. It likewise contains numerous inverted pyramidal bodies, which are believed to be casts of the cavities made in the muddy sand by the rotary movement imparted by tides or currents to crinoids or seaweeds rooted and half buried in it.[2] At the top of the Upper Ludlow rock, near the town of Ludlow, a brown layer occurs, from a quarter of an inch to three or four inches in thickness, full of fragments of fish, *Pterygotus*, and shells. This layer, termed the "Ludlow Bone-bed," is the oldest from which any considerable number of vertebrate remains has been obtained. In spite of its insignificant thickness, it has been detected at numerous localities from Ludlow as far as Pyrton Passage, at the mouth of the Severn—a distance of 45 miles from north to south, and from Kington to Ledbury and Malvern—a distance of nearly 30 miles from west to east; so that it probably covers an area (now largely buried under Old Red Sandstone) not less than 1000 square miles in extent. Yet it appears never to exceed, and usually to fall short of, a thickness of 1 foot. Fish remains, however, are not confined to this horizon, but have been detected in strata above the original bone-bed at Ludlow.

A considerable suite of organic remains has been obtained from the Upper Ludlow rock, which, on the whole, are similar to those in the sub-groups underneath. Some minute globular bodies, with internal radial structure (*Pachytheca*), occur with other plant remains (*Pachysporangium*, *Actinophyllum*, *Chondrites*). Corals, as might be

[1] 'Siluria,' p. 130.

[2] *Op. cit.* p. 133.

supposed from the muddy character of the deposit, seldom occur, though Murchison mentions that the encrusting form *Favosites (Monticulipora) fibrosus* may not infrequently be found enveloping shells, *Cyclonema corallii* and *Murchisonia corallii* being, as their names imply, its favourite habitats. All the corals of the Ludlow group are also Wenlock species. Some annelids (*Serpulites longissimus, Cornulites serpularius*, and *Trachyderma coriaceum*) are not uncommon. The crustacea are represented in the Upper Ludlow rock by ostracods (*Beyrichia Kloedeni, Leperditia marginata, Entomis tuberosa*), phyllocarids (*Ceratiocaris*), and more especially by eurypterids (*Eurypterus, Hemiaspis, Pterygotus, Slimonia, Stylonurus*). The trilobites have still further waned in the Upper Ludlow rock, though *Homalonotus Knightii, Encrinurus punctatus, Phacops Downingiæ*, and a few others still occur, and even the persistent *Calymene Blumenbachii* may occasionally be found. Of the brachiopods, the most abundant forms in this group are *Lingula minima, L. lata, Orbiculoidea rugata, Rhynchonella (Wilsonia) Wilsoni, Strophomena (Stropheodonta) filosa*, and *Chonetes striatella.* The most characteristic lamellibranchs are *Orthonota amygdalina, Goniophora cymbæformis, Pterinea lineata, P. retroflexa;* some of the commonest gasteropods are *Murchisonia corallii, Platyschisma helicites*, and *Holopella obsoleta.* The orthoceratites are specifically identical with those of the Lower Ludlow rock, and are sometimes of large size, *Orthoceras bullatum* being specially abundant. The fish-remains consist of bones, teeth, shagreen-like scales, plates, and fin-spines. They include some dermal tubercules (*Thelodus*), shagreen-scales (*Sphagodus*), and some ostracoderms, *Cephalaspis* (*C.* or *Hemicyclaspis Murchisoni*), *Auchenaspis* (*Thyestis*) (*A. Salteri*), *Cyathaspis* (*C. Banksii, C.? ludensis*), and *Eukeraspis* (*Plectrodus*) (*E. pustuliferus*). Some of the spines described under the name of *Onchus* are probably crustacean.

(*d*) *Tilestones, Downton Castle Stone, and Ledbury Shales.*—Above the Upper Ludlow shales and mudstones lies a group of fine yellow, red, and grey micaceous sandstones from 80 to 100 feet thick which have long been quarried at Downton Castle, Herefordshire. At Ledbury these sandstones are surmounted by a group of red, purple, and grey marls, shales, and thin sandstones, having a united thickness of nearly 300 feet. Originally the whole of these flaggy upper parts of the Ludlow group were called "Tilestones" by Murchison, and, being often red in colour, were included by him as the base of the Old Red Sandstone, into which they gradually and conformably ascend. They point to a gradual change of physical conditions, which took place at the close of the Silurian period in the west of England and brought in the peculiar deposits of the Old Red Sandstone. There is every reason to believe that for a long time the marine sedimentation of Upper Silurian type continued to prevail in some areas, while the probably lacustrine type of the Old Red Sandstone had already been established in others, and that by the breaking down or submergence of the barriers between these different areas, marine and lacustrine conditions alternated in the same region. The Tilestones are the records of this curious transitional time.[1]

Vegetable remains, some of which seem to be fucoids, but most of which are probably terrestrial and lycopodiaceous, abound in the Downton sandstone and passage-beds into the Old Red Sandstone. The eurypterid genera still continue to occur, together with phyllocarids (*Ceratiocaris*) and vast numbers of the ostracod *Beyrichia* (*B. Kloedeni*). Prevalent shells are *Lingula cornea* and *Platyschisma helicites.* The Ludlow fishes are also met with.

In the typical Silurian region of Shropshire and the adjacent counties, nothing can be more decided than the lithological evidence for the gradual disappearance of the Silurian sea, with its crowds of graptolites, trilobites, and brachiopods, and for the gradual introduction of those geographical conditions which brought about the deposit of the

[1] On these passage-beds see Symonds, 'Records of the Rocks,' 1872, pp. 183-215; *Q. J. G. S.* xvi. (1860), p. 193; Roberts and Randall, *op. cit.* xix. (1863), p. 229; also the remarks made on the corresponding strata in Scotland, pp. 942, 965.

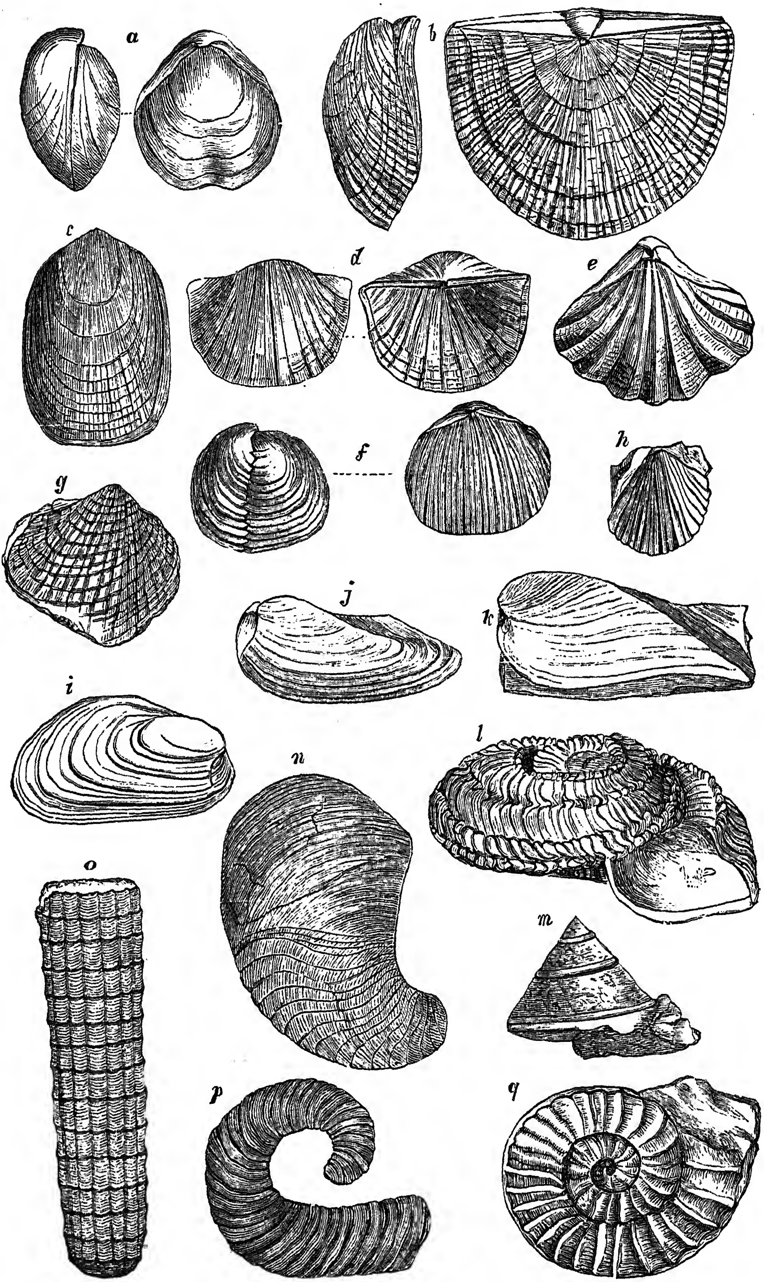

Fig. 382.—Group of Upper Silurian Mollusca.

a, Whitfieldiella (Meristina) didyma, Dalm.; *b*, Strophomena antiquata, Sby.; *c*, Lingula Lewisii, Sby.; *d*, Plectambonites (Leptæna) transversalis, Dalm.; *e*, Rhynchonella borealis, Schloth.; *f*, Rhynchonella Wilsoni, Sby.; *g*, Cardiola interrupta, Brod.; *h*, Ambonychia acuticostata, McCoy; *i*, Modiolopsis Nilssoni, His.; *j*, Orthonota amygdalina, Sby.; *k*, Goniophora cymbæformis, Sby.; *l*, Omphalotrochus (Euomphalus) rugosus, Sby.; *m*, Trochus cælatus, McCoy ($\frac{3}{4}$); *n*, Phragmoceras ventricosum, Sby. ($\frac{1}{4}$); *o*, Orthoceras annulatum, Sby. ($\frac{1}{2}$); *p*, Trochoceras (Lituites) giganteum, Sby. ($\frac{1}{4}$); *q*, Ophidioceras (Lituites) articulatum, Sby.

Old Red Sandstone. The fine grey and olive-coloured muds, with their occasional zones of limestone, are succeeded by bright red clays, sandstones, cornstones, and conglomerates. The evidence from fossils is equally explicit. Up to the top of the Ludlow rocks, the abundant Silurian fauna continues in hardly diminished numbers. But as soon as the red strata begin the organic remains rapidly die out, until at last only the fish and the large eurypterid crustaceans continue to occur.

Turning now from the interesting and extremely important, though limited, area in which the original type of the Upper Silurian rocks is developed, we observe that, whether traced northwards or south-westwards, the limestones disappear, while the soft mudstones and shales give way to hard slates, grits, and flagstones. It is in Denbighshire and the adjacent counties that this change becomes most marked. The Tarannon shale above described passes into that region of North Wales, where it forms the base of the Upper Silurian formations. It is covered by a series of grits, flags, sandstones, mudstones, and shales, which in some places are at least 3000 feet thick. At their base lie the Pen-y-glog slates, containing *Cyrtograptus Murchisoni*, *Monograptus vomerinus*, *M. priodon*, *Retiolites geinitzianus*, *Acrocul̄ia haliotis*, *Orthoceras Sedgwickii*—an assemblage which, no doubt, represents the fauna of the Wenlock shale. Next comes the Pen-y-glog grit, containing plants (*Nematophycus*, *Pachytheca*, and the lycopod referred to on p. 936), and followed by the Moel Ferna slates (*Monograptus priodon*, *M. Flemingii*), the Nantglyn flags (*M. colonus*, *Cardiola*, *Orthoceras primævum*, *O. ventricosum*, *O. Sedgwickii*), further grits and fine hard siliceous bands (*Monograptus leintwardinensis*, the zone fossil at the top of the Lower Ludlow Rock, and other organisms). The highest (Dinas Bran) part of the series may be paralleled with the Upper Ludlow shales.[1] Instead of passing up conformably into the base of the Old Red Sandstone, as at Ludlow, their highest strata are here absent, and they are covered by that formation unconformably. They had been upturned, crumpled, faulted, and cleaved before the deposition of those portions of the Old Red Sandstone (Upper) which lie upon them. These great physical changes took place in Denbighshire when, so far as the evidence goes, there was entire quiescence in the Shropshire district; yet the distance between the two areas was not more than about 60 miles. The subterranean movements were doubtless connected with those more widely extended upheavals that converted the floor of the Silurian sea over the area of Britain into a series of isolated basins, in which the Lower Old Red Sandstone was laid down (pp. 981, 999).

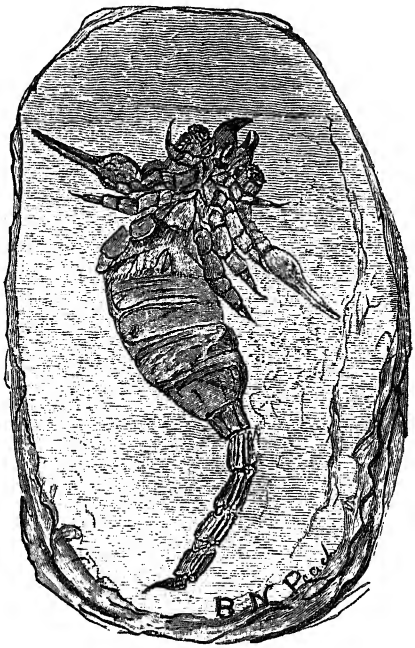

Fig. 383.—Fossil scorpion (*Palæophonus caledonicus*, Hunter), Upper Silurian, Lesmahagow, Lanarkshire (about twice nat. size). Drawn by Mr. B. N. Peach.

Upper Silurian rocks appear in a succession of isolated areas from the Midlands south-westwards to the Bristol Channel. Among these inliers special interest attaches to that of Tortworth in the south of Gloucestershire, where two bands of volcanic

[1] P. Lake, *Q. J. G. S.* li. (1895), p. 9.

materials (basaltic lavas and tuffs) point to volcanic eruptions in that district before the deposition of the Upper Llandovery rocks, and again before Lower Wenlock time. These are the latest Silurian manifestations of volcanic activity yet found in the British Isles.[1].

In Westmoreland and Cumberland a vast mass of hard slates, grits, and flags was identified by Sedgwick as of Upper Silurian age. These form the varied ranges of hills in the southern part of the Lake District, from near Shap to Duddon Mouth. The following are the local subdivisions, with the conjectural equivalents in Siluria:[2]—

Kirkby Moor Flags Hay Fell Flags (2000 feet).	Thick beds of hard sandstone, massive and concretionary or flaggy and micaceous (*Phacops Downingiæ*, *P. caudatus*, *Ceratiocaris inornatus*, *Lingula cornea*, *Orthis lunata*, *Orthonota amygdalina*, *Holopella gregaria*, *H. conica*).	= Upper Ludlow Group
Bannisdale Flags (5200 feet).	Calcareous beds (*Dayia navicula* abundant) probably equivalent to the Aymestry Limestone. Sandstone and Shale, with star-fishes (*Protaster*). Dark blue flags and grits of great thickness.	= Middle Ludlow Group
	(*Monograptus leintwardinensis* ranges through the Bannisdale Flags and *M. colonus* and *M. Salweyi* also occur.)	= Lower Ludlow Group
Coniston Grits (upwards of 4000 feet).	Flags and greywacke generally unfossiliferous, but containing *Monograptus colonus*, *M. bohemicus*, *M. Roemeri*, *Cardiola interrupta*, *Orthoceras angulatum*, *O. primævum*, *Ceratiocaris Murchisoni*.	
Coniston Flags (2800 feet).	Dark grey coarse flags divided by Sedgwick into stages which are characterised by Mr. Marr as follows: Upper Coldwell Beds (lower part of zone of *Monograptus bohemicus*) with *M. colonus*, *M. Roemeri*, *Spirorbis Lewisii*, *Ceratiocaris Murchisoni*, *Encrinurus punctatus*, *Phacops Stokesii*, *Cardiola interrupta*, *Pterinea subfalcata*, *Orthoceras primævum*, *O. dimidiatum*, *O. subundulatum*, *O. ludense*. Middle Coldwell Beds (zone of *Phacops obtusicaudatus*) with *Cardiola interrupta*, *Orthoceras subannulare*, *O. angulatum*, *O. lineatum*, *O. inbricatum*. Lower Coldwell Beds (zone of *Monograptus Nilssoni*).	
	Brathay Flags (zone of *Cyrtograptus Murchisoni*), fossils chiefly graptolites including *Monograptus priodon*, *M. vomerinus*, *M. cultellus*, *Retiolites geinitzianus*, *Aptychopsis*, *Cardiola interrupta*, *Orthoceras primævum*. Thickness more than 1000 feet.	Wenlock Group.
Stockdale Shales (200-450 feet).	Browgill Beds: Upper pale green and purple shales with badly preserved fossils, 67 feet. Lower pale shales (65 feet) with zones of *Monograptus crispus* and *M. turriculatus*. Skelgil Beds or Graptolitic Mudstones: Upper blue mudstones with two bands of black and blue graptolitic shale, the upper of which contains *Monograptus spinigerus*, the lower *M. Clingani*. Middle blue mudstones with three bands of dark graptolitic shale, the highest being the zone of *Monograptus convolutus*, (with *M. gregarius*, *M. Clingani*, *Rastrites peregrinus* and many other graptolites), the middle being the zone of *Monograptus argenteus* (with *M. gregarius*, *M. leptotheca*, and ten other species; *Rastrites peregrinus*, and three other species; *Diplograptus tamariscus*, *D. Hughesii*, *Climacograptus normalis*, and other fossils); and the lower band being the zone of *Monograptus fimbriatus*, *M. gregarius*, *M. tenuis*, and other species; *Rastrites peregrinus*, *Diplograptus tamariscus*, *Petalograptus ovatus*, *Climacograptus normalis*. Lower calcareous shales = zone of *Dimorphograptus confertus*, with *Monograptus revolutus*, *M. tenuis*, *Diplograptus vesiculosus*, &c., resting on a thin limestone with *Atrypa flexuosa*.	= Llandovery Group.

In some places beneath these shales a conglomeratic band occurs that forms their base and lies unconformably on Lower Silurian strata.

In the northern part of the Lake District a great anticlinal fold has taken place. The

[1] Professor Lloyd Morgan and S. H. Reynolds, *Q. J. G. S.* lvii. (1901), p. 267.

[2] For papers on the Upper Silurian rocks of the Lake District see R. Harkness and H. A. Nicholson, *Q. J. G. S.* xxiv. (1868), p. 296; xxxiii. (1877), p. 461. Nicholson, *op. cit.* p. 521; xxviii. (1872), p. 217, 'An Essay on the Geology of Cumberland and Westmoreland, 1868. Nicholson and Lapworth, *Brit. Assoc.* 1875, sects. p. 78. Aveline and Hughes, Geol. Survey Memoirs, *Explanations of Sheet* 98, S.E. and N.E. 1872. Marr, *Q. J. G. S.* xxxiv. (1878), p. 871; *Geol. Mag.* 1892, pp. 97, 534. Marr and Nicholson, *Q. J. G. S.* xliv. (1888), p. 654.

Skiddaw slates arch over and are succeeded by the base of the volcanic series above described. But before more than a small portion of that series has appeared, the whole Silurian area is overlapped unconformably by the Carboniferous Limestone. It is necessary to cross the broad plains of Cumberland and the south of Dumfriesshire before Silurian rocks are again met with. In this intervening tract, a synclinal fold must lie, for in the south of Scotland a broad tract of Upper Silurian strata is now known to form the greater part of the pastoral uplands which stretch from the Irish Sea to the North Sea. Its northern limit where it rests conformably upon and passes down into the Caradoc group, extends from a little south of Port Patrick north-eastwards to near Dunbar. The strata throughout this region have been thrown into innumerable folds which are often reversed. The result of this disturbance has been to compress the rocks into highly inclined positions, and to keep the same group at the surface over a great breadth of ground, so that in spite of their steep angles of dip the strata are made to occupy as much space on the map as if they were almost flat. Here and there, where the anticlines are more pronounced and denudation has proceeded far enough, long boat-shaped inliers of Lower Silurian rocks have been laid bare underneath the upper series of formations. In this way the Llandeilo volcanic group (p. 951) can be traced by occasional exposures for some 90 miles to the north-eastward from the Ayrshire coast, where it is most largely developed. By far the larger part of the Uplands is formed of rocks which, from the researches of Professor Lapworth among their graptolitic contents, are now known to be the general equivalents of the Llandovery and Tarannon groups.[1] In the central part of the region the Llandovery rocks are represented by greywackes and shales, including the black graptolitic Birkhill shales which form two bands separated by alternations of grey and green shales, and are subdivided as follows in ascending order:—

Lower Birkhill.	1. Zone of *Diplograptus acuminatus* with *Dimorphograptus elongatus? Monograptus attenuatus*, *M. tenuis*.
	2. Zone of *Diplograptus vesiculosus*, with *Monograptus cyphus*, *M. tenuis*.
	3. Zone of *Monograptus gregarius*, with *M. fimbriatus*, *M. convolutus*, *Diplograptus folium*, *Rastrites peregrinus*, &c.
Upper Birkhill.	1. Zone of *Monograptus Clingani*, with *M. crenularis*, *M. Sedgwicki*, *Petalograptus cometa*.
	2. Zone of *Monograptus spinigerus* (*M. distans*, &c.).
	3. Zone of *Rastrites maximus* (*Monograptus turriculatus*, &c.).

The Tarannon group of the same district, consisting of shales, flagstones, greywackes, and grits, with bands of conglomerate, contains some of the Birkhill graptolites, others which pass up into the Wenlock series (*Monograptus exiguus*, *M. crispus*, *M. vomerinus*, &c.), and a few which appear to be mainly if not exclusively confined to this group (*M. turriculatus*, *M. exiguus*, *M. crispus*, *M. pandus*). In Ayrshire the equivalent strata present a much greater diversity of sedimentation, thick masses of conglomerate, limestone, and calcareous shale being conspicuous. In that district accordingly there is so marked a contrast in the abundance and variety of the organic remains, that the strata may be compared with the more fossiliferous deposits of the original and typical Silurian region. Representatives of the Wenlock and Ludlow groups are traceable along both sides of the Silurian region. In Lanarkshire these strata have been long celebrated for the number and variety of their merostomata (*Eurypterus*, 3 species; *Pterygotus*, 2; *Slimonia*, 1; *Stylonurus*, 1; *Neolimulus*, 1). They have also yielded the scorpion (Fig. 383) and the myriapod already referred to (p. 943). Above the Ludlow rocks of the Pentland Hills, Lanarkshire, and Ayrshire lies a conformable group of red and yellow sandstones, mudstones, and conglomerates which were formerly regarded as the base of the Old Red Sandstone. But the discovery in them of a tolerably abundant marine fauna, identical with that of the uppermost Silurian strata,

[1] See Lapworth, *Quart. Journ. Geol. Soc.* xxxiv. (1878), xxxviii. (1882); *Geol. Mag.* 1889, pp. 20, 59; *Ann. Mag. Nat. Hist.* 1879, 1880. Also the descriptions by Messrs. Peach and Horne in the detailed Memoir of the Geological Survey, already cited on p. 950.

has led to their being placed at the top of the Silurian series. They are probably equivalents of the Tilestones and Downton Sandstone. Their chief palæontological interest is the discovery in them of five genera of fishes, some of which have not been found elsewhere (p. 942).

The Scottish type of the Upper Silurian formations is prolonged south-westwards into Ireland, where the Llandovery group of Birkhill has been recognised not only in Down, but in Tyrone, Fermanagh, and other counties. Evidence of contemporaneous volcanic action has been obtained from the Silurian rocks of the east of Ireland.[1] Upper Silurian rocks representing the Llandovery and Wenlock formations attain an enormous development in the west of Ireland. In the picturesque tract between Lough Mask and Killary Harbour, where they reach a thickness of more than 7000 feet, they consist of massive conglomerates, sandstones, and shales, with Llandovery and Wenlock fossils and intercalated felsites, diabases, and tuffs. Again, in the Dingle promontory of County Kerry, Upper Silurian strata full of Wenlock fossils contain the most impressive proofs of contemporaneous volcanic action; agglomerates, tuffs, and volcanic blocks being intermingled with the fossiliferous strata, which are further separated by thick sheets of nodular felsitic lavas.[2]

Basin of the Baltic, Russia, and Scandinavia.[3]—The broad depression which, running from the mouth of the English Channel across the plains of Northern Germany into the heart of Russia, divides the high grounds of the north and north-west of Europe from those of the centre and south, separates the European Silurian region into two distinct areas. In the northern of these we find the Lower and Upper Silurian formations attaining an enormous development in Britain, but rapidly diminishing in thickness towards the north-east, until in the south of Scandinavia and the Gulf of Finland, they reach only about $\frac{1}{25}$th of that depth. Along the Baltic shores, too, they have on the whole escaped so well from the dislocations, crumplings, and metamorphism so conspicuous along the north-western European border, that to this day they remain over wide spaces nearly as horizontal and soft as at first. In the southern European area, Silurian rocks appear only here and there from amidst later formations, and almost everywhere present proofs of intense subterranean movement. Though sometimes attaining considerable thickness they are much less fossiliferous than those of the northern part of the region, except in the basin of Bohemia, where an exceedingly abundant series of Silurian organic remains has been preserved.

In Russia, Silurian rocks must underlie the whole vast breadth of territory between the Baltic and the flanks of the Ural Mountains, beyond which they spread eastward into Asia. Throughout most of this extensive area they lie in horizontal undisturbed beds, covered over and concealed from view by later formations. Along the southern margin of the Gulf of Finland, they appear at the surface as soft clays, sands, and unaltered strata, which, so far as their lithological characters go, might be supposed to be of late Tertiary date, so little have they been changed during the enormous lapse of ages since Lower Palæozoic time. The great plains bounded by the Ural chain on the

[1] A. G., *Q. J. G. S.* xlvii. (1891), Presidential Address, p. 150; 'Ancient Volcanoes of Great Britain,' vol. i. and authorities there cited. *Summary of Progress Geol. Surv.* 1900, pp. 51-59.

[2] *Q. J. G. S.* xlvii. p. 159, and authorities cited. Consult on Irish Silurian rocks the Explanations to the one-inch Sheets of the Geological Survey.

[3] Consult the works of Angelin and Kjerulf, already cited (p. 924); Linnarsson, *Svensk. Vet. Akad.* viii. No. 2; *Zeitsch. Deutsch. Geol. Gesell.* xxv. p. 675; *Geol. Mag.* 1876, pp. 145, 240, 287, 379; *Geol. Föreningens Stockholm Förhandl.* 1872-74, 1877, 1879. S. L. Törnquist, *Kong. Vet. Akad. Förhandl.* 1874, No. 4; *Geol. Fören. Stockholm Förhandl.* 1879. Lundgren, *Neues Jahrb.* 1878, p. 699. Brögger, 'Die Silurischen Etagen 2 und 3 im Kristiania Gebiet,' 1882. F. Schmidt, *Q. J. G. S.* 1882, p. 514. J. E. Marr, *Q. J. G. S.* 1882, p. 313. A. G. Nathorst, 'Sveriges Geologi,' Part. i. 1892, and papers cited below.

east, by the uplands of Finland and Scandinavia on the north, and by the rising grounds of Germany on the south-west, have thus from a remote geological antiquity been exempted from the terrestrial corrugations that have affected so much of the rest of Europe. They have been alternately, but gently, depressed as a sea-floor, and elevated into steppes or plains. But along the flanks of the Ural Mountains, the older Palæozoic rocks have been upheaved and placed on end or at a high angle against the central portions of that chain; and, according to the observations of Murchison, Keyserling, and De Verneuil, have been partially metamorphosed into chlorite-schists, mica-schists, quartzites, and other crystalline rocks. To the north-west also, over a vast region in Scandinavia, they have been subjected to gigantic displacements and great regional metamorphism (pp. 693, 798, 925).

Taking first their unaltered condition, we find them well exposed along the southern shores of the Gulf of Finland, in the Baltic provinces of Russia, where, according to F. Schmidt, they form with the Cambrian groups below them one continuous and conformable series, capable of arrangement as in the subjoined table:[1]—

Upper Silurian.

Stage K. Upper Oesel Zone (50 or 60 ft. = Ludlow Group)—grey limestones and marls, yellow limestones: *Spirifer elevatus*, *Chonetes striatella*, *Beyrichia tuberculata*, *Pterinea retroflexa;* an abundant eurypterid fauna and fish remains (*Onchus*, *Thelodus*).

„ I. Lower Oesel Zone (60 ft. = Wenlock)—chiefly dolomites with marls: *Orthoceras annulatum*, *Omphalotrochus globosus* (*Euomphalus funatus*), *Spirifer crispus*, *Orthis elegantula*, *Plectambonites* (*Leptæna*) *transversalis*.

„ H. Pentamerus-esthonus Zone—in the east, dolomites; in the west, grey coral limestone, with *Pentamerus esthonus* (*oblongus*), *Syringopora bifurcata*, *Favosites gotlandica*, *Halysites* (5 sp.).

„ G.
3. Raiküll Beds (100 ft.)—coral-reefs and flagstones: *Leperditia Keyserlingii*, *Phacops elegans*.
2. Borealis Bank (40 ft.—consisting almost entirely of agglomerated shells of *Pentamerus borealis*.
1. Jörden Beds (20–30 ft.)—thin calcareous flagstones and marls: *Leperditia Hisingeri*, *Orthis Davidsoni*, *Strophomena* (*Orthothetes*) *pecten*, *Rhynchonella affinis*.

Lower Silurian.

„ F. (1) Lyckholm and (2) Borkholm Zones (100 ft. = Middle Bala or Caradoc), contain the most abundant fauna of all the stages: *Phacops* (*Chasmops*) *macroura*, *Cheirurus octolobatus*, *Encrinurus multisegmentatus*, *Bellerophon bilobatus*, *Strophomena expansa*, *Orthis vespertilio*, *O. Actoniæ*, *O. insularis*. The limestones of this platform are in great part formed of calcareous algæ (*Rhabdoporella*).

„ E. Wesenberg Zone (30 ft. = Bala or Caradoc)—hard yellowish limestone, with marly partings: *Plectambonites* (*Leptæna*) *sericea*, *Strophomena deltoidea*, *Orthis testudinaria*, *Phacops Nieszkowskii*, *P. wesenbergensis*, *Encrinurus Seebachi*, *Cybele brevicauda*.

„ D. Jewe Zone (100 ft.), consisting of a lower or Jewe band and an upper or Kegel band: *Cheirurus pseudohemicranium*, *Hemicosmites extraneus*, *Lichas deflexa*, *L. illænoides*, *Chasmops bucculenta*, *Strophomena Asmusii*.

„ C.
3. Itfer Beds (20–30 ft.)—hard limestone with siliceous concretions; fauna nearly same as in C. 2, but with some peculiar trilobites, and some forms belonging to Stage D.
2. Kuckers Shale (Brandschiefer), consisting of bituminous marls and limestones (30–50 ft.): *Phacops exilis*, *P.* (*Chasmops*) *Odini*, *Cheirurus spinulosus*, *Pleurotomaria elliptica*, *Porambonites teretior*, *Orthis lynx*, *Echinosphærites* (*Echinosphæra*) *aurantium*.
1. Echinosphærite Limestone, &c. (20–50 ft. = uppermost Orthoceratite Limestone of Sweden)—*Echinosphærites aurantium*, and *Orthoceras regulare* are the most characteristic fossils, with numerous trilobites.

[1] *Mem. Ac. Imp. St. Pétersb.* (7) xxx. (1881), No. 1; *Q. J. G. S.* xxxviii. 1882, p. 514; *Neues Jahrb.* 1893, i. p. 99.

Stage B
3. Orthoceratite (Vaginaten-) Limestone (3–30 ft. = Orthoceras limestone of Scandinavia)—hard grey limestone crowded with *Orthoceras commune* and *O. vaginatum*; also *Phacops sclerops*, *Cheirurus ornatus*, *Asaphus heros*, *Ampyx nasutus*, &c.
2. Glauconite Limestone (12–40 ft.)—*Megalaspis planilimbata*, *Cheirurus clavifrons*, *Asaphus expansus*, *Porambonites reticulatus*, *Orthis parva*.
1. Glauconite Sand (Greensand), lying directly on the Cambrian Dictyonema shale (1–10 ft. = Ceratopyge Stage of Scandinavia) —*Obolus siluricus*, *Siphonotreta*, *Lingula*; "conodonts" of Pander.

Fossiliferous Silurian strata must extend across the vast territory of Northern Russia, for they not only occur in the Ural Mountains but have recently been found by Nansen along the shores of the Yugor Strait in the Kara Sea, where they include brachiopods (among them the widespread *Plectambonites* (*Leptæna*) *sericea* and species of *Orthis* and *Strophomena*) also trilobites (*Megalaspis*, *Asaphus*, *Remopleurides*), indicating probably a horizon equivalent to that of C. 1 *a* in the Baltic provinces, or Stage 4 *α α* in Norway.[1]

In Scania, the Silurian series has been subdivided into graptolitic zones as in the subjoined table:[2]—

Upper Silurian.
A. Upper Group[3]—Cardiola shales, with limestone and sandstone.
B. Middle Group, with the following zones in descending order: (*a*) *Cyrtograptus Carruthersi*; (*b*) *C. rigidus*; (*c*) *C. Murchisoni*; (*d*) *Monograptus riccartonensis*; (*e*) *Cyrtog. Lapworthii*; (*f*) *C.* (?) *spiralis*; (*g*) *C. Grayæ*.
C. Lower Group, composed of the following zones in descending order: (*a*) *Monograptus cometa*; (*b*) Grey unfossiliferous shales; (*c*) *Cephalograptus cometa*; (*d*) *Mon. leptotheca*; (*e*) *M. gregarius*; (*f*) *M. cyphus*.

Lower Silurian.
D. Upper Group, composed of the following zones in descending order: (*a*) *Diplograptus*, sp.; (*b*) *Phacops mucronata*; (*c*) *Staurocephalus clavifrons*; (*d*) Unfossiliferous marly shales; (*e*) *Niobe lata*; (*f*) Unfossiliferous shales; (*g*) *Diplograptus quadrimucronatus*; (*h*) *Trinucleus*, sp.; (*i*) *Calymene dilatata*; (*k*) Unfossiliferous shales.
E. Middle Group—Graptolite shales, with zones of (*a*) *Climacograptus rugosus*; (*b*) *C. styloideus*; (*c*) Black unfossiliferous shales; (*d*) Limestone band, with *Ogygia*, sp.; (*e*) *Dicranograptus Clingani*; (*f*) *Climacograptus Vasæ*; (*g*) Unfossiliferous shales; (*h*) *Cœnograptus gracilis*; (*i*) Thin apatitic band; (*k*) *Diplograptus putillus*; (*l*) *Glossograptus*; (*m*) *Gymnograptus Linnarssoni*; (*n*) *Glossograptus*; (*o*) *Didymograptus geminus* (*Murchisoni*).
F. Lower Group, composed of the zones of (*a*) *Phyllograptus*, sp.; (*b*) Orthoceras limestone; (*c*) Tetragraptus shales (lower graptolite shales); (*d*) Ceratopyge limestone.

The island of Gothland has long been celebrated for its development of Upper Silurian rocks, which are there more fully displayed than in any other part of the Baltic basin. According to Lindström[4] the following subdivisions of them may be made:—

Ludlow.
H. Cephalopod and Stromatopora-Limestone (20–30 feet) with *Phragmoceras*, *Ascoceras*, *Glossoceras*. The *Stromatopora* forms a reef like a modern coral-reef.
G. Megalomus-Limestone (8–12 feet) with *Cyrtodonta* (*Megalomus*) *gotlandicus*, *Trimerella*.
F. Crinoidal and Coral conglomerate (20 feet), a limestone made up of stems of crinoids, corals, and other fossils. Among the crinoids are species of *Crotalocrinus*, *Enallocrinus*, *Barrandeocrinus*, *Cyathocrinus*; there

[1] J. Kiær, in Nansen's 'North Polar Expedition,' iv. No. xii. (1902).

[2] S. A. Tullberg, 'Skänes Graptoliter,' *Sverig. Geol. Undersöken. ser.* C. No. 50, 1882-83.

[3] A full list of the fossils of the highest Upper Silurian deposits of Scania is given by K. A. Grönwall, *Geol. Fören, Stockholm*, xix. (1897), p. 188.

[4] *Neues Jahrb.* 1888, i. p. 147, and F. Schmidt, *op. cit.* 1890, ii. p. 249. Murchison, *Q. J. G. S.* 1847. H. Munthe, *Sverig. Geol. Undersökn.* ser. C. No. 192 (1902).

occur also *Spirifer Schmidti*, *Pentamerus conchidium*. This band lies somewhere about the horizon of the Aymestry Limestone.

E. Pterygotus-clay or marl (1–2 feet) with abundant fragments of *Pterygotus osiliensis*, also *Phasganocaris*, *Strophomena*, *Eatonia*, *Conularia*, &c.

Wenlock.

D. Limestone, oolite and marly bands (50 feet) with numerous lamellibranchs; species of *Pterinea*, *Aviculopecten*, and *Grammysia*, also *Orthis basalis*, *O. biforata*, and *Atrypa Angelini*, *Lichas*, *Cyclonema delicatulum*, &c.

C. Younger marly shales and sandstone (100 feet), with a large and varied assemblage of fossils like those of the Wenlock Shale (*Phacops Downingiæ*, *P. vulgaris*, *Homalonotus Knighti*, *Strophomena euglypha*, *Orthis biloba*, *Strophomena Walmstedti*, *Rhynchonella Wilsoni*, *Orthoceras annulatum*, *O. gregarium*, *Monograptus ludensis*, *M. colonus*, *Retiolites geinitzianus*, &c.

Llandovery.

B. Stricklandinia-marl (8 feet) with *Heliolites*, *Plasmopora*, *Halysites*, *Bronteus platyactin*, *Calymene papillosa*, *C. frontosa*, *Orthis Davidsoni*, *O. Lovéni*, and especially the abundant *Stricklandinia lirata*.

A. Older red marly shales (thickness unknown) with some 40 species of fossils, among which are *Favosites gotlandica*, *F. Forbesi*, *Halysites*, *Plasmopora*, *Arachnophyllum diffluens*, &c.

In the Christiania district, the following subdivisions in the Silurian formations have been established:—

Upper.

Stage 8.
- γ. Compact grey, often bituminous limestone, with abundant *Orthoceras cochleatum* and *Chonetes striatella*.
- β. Grey, somewhat bituminous limestone, with shales and clays.
- α. Fissile green or grey marly shales containing the last graptolites. This and the two overlying members have a united depth of 835 Norwegian feet at Ringerige.

Stages 6 & 7. Coral limestone and Pentamerus limestone.

Lower.

Stage 5. Calcareous sandstone, with *Rhynchonella diodonta* and shales (Brachiopod-shales), 150 to 370 feet.[1]

,, 4. Shales and marls, with nodules and short beds of cement-stone (*Trinucleus*, *Chasmops*), 700 feet.

,, 3. Graptolite shales, Limestone in two or more bands (Orthoceras-, Asaphus-, Megalaspis-limestone), 250 feet in places, resting upon the alum-shales of the Primordial zone. This stage has been subdivided by Brögger as follows :—

3 *c*
- 3 *c* γ. *Orthoceras*-limestone, 8 to 13 feet.
- 3 *c* β. *Expansus*-shales, 10 to 15 feet.
- 3 *c* α. *Megalaspis*-limestone, 3 to 4 feet.

3 *b* *Phyllograptus*-shales, 8 to 80 feet.

3 *a*
- 3 *a* γ. *Ceratopyge*-limestone, 3 to 5 feet.
- 3 *a* β *Ceratopyge*-shales, 3 to 23 feet.
- 3 *a* α *Symphysurus*-shale and limestone, 1 to 20 feet.

Beneath these formations lie the zones of *Olenellus* (1 *b*), *Paradoxides* (1 *c*, *d*) and *Olenus* (2 *a*-*d*) of the Cambrian system already referred to (p. 924). The fossils of the three sub-groups that make up group 3 *a* form the *Euloma-Niobe* fauna (p. 922), and are probably equivalent to the Tremadoc group of Wales. The *Phyllograptus*-shales (3 *b*) are crowded with Arenig graptolites.

In the great band of older Palæozoic strata which has been already referred to as stretching for a long distance through the heart of the Scandinavian peninsula, the recognisable Cambrian zones are followed in Jemtland by representatives of the Lower Silurian subdivisions of Southern Sweden and Norway. The Olenus group (p. 924) is covered by the *Phyllograptus*-shales (3 *b*), with species of *Tetragraptus*, *Didymograptus*, *Phyllograptus* and other genera. These strata pass under the *Orthoceras*-limestone, in which can be recognised the zones of *Megalaspis limbata* (3 *c* α), *Asaphus expansus* (3 *c*, β), *Megalaspis gigas*, and *Asaphus platyurus* (3 *c* γ). Next come some black shales with *Cheirurus*, *Ogygia*, *Trinucleus*, *Illænus*, *Ampyx*, *Chasmops*, &c. (4), followed by grey sandstones

[1] This stage has been the subject of detailed study by Mr. J. Kiær. *Videnskab Skrift. Christiania*, 1897, No. 3; *Norges. Geol. Undersög. Aarbog* for 1902.

and shales with brachiopods, *Encrinurus*, *Ampyx*, *Æglina*, &c. (5), probably the uppermost division of the Lower Silurian formations. It is interesting, however, to note that the lower portion of the Upper Silurian series has also been detected in Jemtland, where it is represented by a dark *Pentamerus*-limestone with numerous fossils lying on a quartzite containing *Phacops*, and by some upper shales full of graptolites (*Cyrtograptus*, *Diplograptus*, *Retiolites*) and a number of species of *Monograptus* (*M. discus*, *Flemingii*, *jaculum*, *lobifer*, *priodon*, *tortilis*, &c.).[1]

When the ground along the western side of the Scandinavian axis is examined the older Palæozoic strata present a remarkably different development from that of the southern part of the peninsula.[2] In the Jemtland region just noticed it can be seen that the lithology of the formations was even originally very different, and that within that region great variations in the nature of the materials can be traced. These initial divergences, however, have been greatly aggravated by subsequent regional metamorphism. According to the researches of Kjerulf, Dahll, Törnebohm, Brögger, Reusch, and other geologists, vast masses of quartzite, mica-slate, gneiss, hornblende-schist, clay-slate, and other crystalline rocks can be seen reposing upon recognisable Silurian strata in numerous natural sections. As an example of this structure the subjoined section is taken from the Hardanger district as observed by Brögger:[3]—

5. Various crystalline schists, hälleflint, mica-schist, hornblende-schist, gneiss, &c.	300 metres.
4. Greyish green phyllite	220 ,,
3. Impure marble	10 ,,
2. Quartzite ("blue quartz")	40 ,,
1. Alum-slate	45 to 50 ,,
Pre-Cambrian granites, gneisses, and other crystalline schists.	

The alum-slate has been changed by regional metamorphism into a glossy bluish-black puckered phyllitic material, but shows in its upper parts layers containing recognisable *Dictyograptus flabelliformis*. There cannot therefore be any doubt as to the position of this band in the stratigraphical series. The quartzite retains still much of its original character as an ordinary siliceous sandstone, and may be taken to be an equivalent of the lower part of Stage 3 of the Christiania district. The marble is probably an altered orthoceras-limestone (Stage 3 *c*). The phyllite (4) has originally been a shale, perhaps that of Stage 4. The hälleflint rocks at the bottom of the overlying gneisses were no doubt originally felspathic sandstones (sparagmite); the hornblende-schists were, perhaps, partly marl-slates, partly highly basic igneous rocks; the mica-schists are for the most part highly altered shales. These overlying crystalline schists, like those of the Scottish Highlands, may not only consist of metamorphosed Cambrian and Silurian sedimentary formations, but may not improbably include also portions of different pre-Cambrian systems which, together with the Palæozoic strata, have been subjected to such great disturbance as to have had a new crystalline structure superinduced upon them. Enormous displacements and lateral thrusts have driven the crystalline rocks over the fossiliferous strata, as in Scotland, but the details of this structure, which has been long recognised by Törnebohm, have still to be worked out. As regards the date

[1] C. Wiman, *Bull. Geol. Inst. Upsala*, i. No. 2, 1893.

[2] See Dahll, *Förh. Vedensk-Selskab.* Christiania, 1867. Kjerulf, 'Norges Geologi,' 1879. Törnebohm, *Bihang Svensk. Akad. Handl.* i. No. 12 (1873); *Geol. För. Stockholm*, vi. (1883), p. 274; xiii. (1891), p. 37; xiv. (1892), p. 27; *Nature*, xxxviii. (1888), p. 127. Brögger, 'Die Silurisch. Etage.' p. 352; 'Lagfölgen på Hardangervidda,' *Norg. Geol. Undersög.* No. 11 (1893). Pettersen, *Tromsö Museums Aarsheft*, vi. (1883), p. 87. F. Svenonius, *Neues Jahrb.* (i.) 1882, p. 181. Nathorst, 'Sveriges Geologi,' p. 141.

[3] The overlying gneisses, &c. in this section, as already stated, are now admitted to have been thrust over the Cambro-Silurian strata, which acted as a kind of lubricating material that moved relatively both to the older rocks above and below. See p. 798 and authorities there cited.

of these great earth-movements and metamorphism, it is important to remember that, as already stated (p. 798), Upper Silurian fossils have been found by Reusch at Bergen in the crystalline schists themselves, as well as in the limestones intercalated in and underlying them. Abundant encrinites have also been found in limestone lenses among the green schists around Sulitelma in the heart of the central mountains of the peninsula.[1]

Western Europe.—The researches principally of Gosselet and Malaise have demonstrated that a considerable part of the strata grouped by Dumont in his "Terrain Rhénan," and generally supposed to be of Devonian age, must be relegated to the Silurian series.[2] Though almost concealed by younger formations, the Silurian rocks that are laid bare at the bottom of the valleys of the Ardennes can be paralleled in a general way as under:—

Upper Silurian.	Ludlow.	Equivalents of the Ludlow rocks seen in the valley of the Fuette between Fosse and Malonne, containing *Monograptus colonus, M. Nilssoni, Retiolites geinitzianus, Orthoceras, Cardiola interrupta*, &c.[3]
	Wenlock.	Brown sandy shales of Naninne, with *Cyrtograptus Murchisoni, Monograptus bohemicus, M. Nilssoni, M. priodon, M. vomerinus, Retiolites geinitzianus, Cardiola interrupta, Orthoceras*, &c.
	Llandovery.	Quartzites and sandstones of Grand-Manil, with *Monograptus bohemicus, M. galaensis?, M. priodon, M. proteus, M. subconicus.* Shales overlying the eurites of Grand-Manil, and containing *Climacograptus normalis, C. rectangularis, Dimorphograptus elongatus, D. Swanstoni, Diplograptus modestus, Monograptus gregarius, M. leptotheca, M. tenuis.*
Lower Silurian.	Caradoc.	*Schistes de Gembloux;* pyritous black and greenish shales, which at Grand-Manil, in the valley of the Orneau, have yielded *Calymene incerta, Trinucleus seticornis, Illænus Bowmanni, Bellerophon bilobatus, Leptæna (Strophomena) rhomboidalis, Orthis testudinaria, O. vespertilio, O. calligramma, O. Actoniæ, Climacograptus caudatus, C. styloideus, C. tubuliferus*, and many more.
		The horizon of the Llandeilo rocks is doubtfully represented at Sart-Bernard.
	Arenig.	Graptolitic shales, with *Climacograptus antennarius, C. Scharenbergi, Dichograptus octobrachiatus, Didymograptus Murchisoni, D. nanus, Diplograptus foliaceus, D. tricornis, Phyllograptus angustifolius, P. typus, Tetragraptus bryonoides*, &c.
		Upper Cambrian horizons are represented at Spa and elsewhere by *Dictyonema sociale.*

The Silurian rocks of Belgium comprise several contemporaneously erupted masses of porphyrite and of diabase, as well as beds of porphyroid, arkose, and eurite.

Silurian rocks have been detected in many parts of the old Palæozoic ridge of the north-west of France. The order of succession in Ille-et-Vilaine is as under:[4]—

[1] H. Sjögren, *Geol. Fören. Stockholm* xxii. (1900), p. 105; P. J. Holmquist, *Sverig. Geol. Undersök., ser.* C. No. 185 (1900).

[2] Gosselet, 'Esquisse Géologique du Nord de la France,' p. 34; 'L'Ardenne,' *Mém. Carte Géol. France* (1888), p. 137. Mourlon, 'Géol. de la Belgique,' p. 40. Malaise, *Mém. Couronn. Acad. Roy. Belgique*, 1873; *Bull. Acad. Roy. Belg.* xx. (1890), p. 440; xxxiii. (1897), No. 6; *Compt. rend. Congr. Géol. Internat. Paris*, 1900, p. 562. C. Barrois, *Ann. Soc. Géol. Nord*, xx. (1892), p. 75, with references to the literature of French Silurian geology.

[3] Full lists of Silurian fossils from Belgium are given by Malaise in the paper of 1900 above quoted.

[4] De Tromelin and Lebesconte, *B. S. G. F.* (1876), p. 585; *Assoc. Franç.* (1875); *Bull. Soc. Linn. Normandie* (1877), p. 5. See also Dalimier, 'Stratigraphie des Terrains primaires dans la presqu'ile de Cotentin,' Paris (1861); *B. S. G. F.* (1862), p. 907. De Lapparent, *B. S. G. F.* (1877), p. 569. Barrois, *Ann. Soc. Géol. Nord*, iv. vii. xix. (1891), p. 134; xx. (1892), pp. 75-193; *B. S. G. F.* (4) i. (1901), p. 637; *Bull. Cart. Géol. France*, No. 7, 1890.

Upper Silurian.	Ludlow.	The existence of the Ludlow formation in Brittany is indicated by graptolites, particularly by the disappearance of *Cyrtograptus* and the predominance of the *Monograptus colonus* type.
	Wenlock.	White limestone of Erbray (*Calymene Blumenbachii, Harpes venulosus*).
		Ampelitic (carbonaceous) limestone of Briasse (*Monograptus priodon, M. Hisingeri, M. colonus, M. vomerinus, M. jaculum*).
		Sandy and ferruginous nodules of Martigné-Ferchaud, Thourie, &c. (*Cardiola interrupta, Monograptus priodon*). The presence of the Wenlock group among the strata that underlie and have been overthrust above the Coal-measures in the Pas de Calais, has now been demonstrated by fossil evidence, these strata having been formerly regarded as belonging to the Carboniferous limestone.[1]
	Tarannon.	Ampelitic (carbonaceous) shales of Poligné (*Monograptus crassus, M. Halli, M. priodon, M. jaculum, M. convolutus, M. continens, Diplograptus palmeus, Petalograptus folium, Retiolites geinitzianus*).
	Llandovery.	Phtanites of Anjou (*Monograptus convolutus, M. crenularis, M. lobiferus, M. sublobiferus, M. Sedgwicki, M. cyphus, M. crispus, M. Clingani, Petalograptus folium, Diplograptus Hughesi, Rastrites peregrinus, R. Linnæi*).
Lower Silurian.	Llandeilo and Bala.	Slates of Riadan (*Trinucleus Pongerardi*).
		Sandstones (Grès de May, Thourie, Bas-Pont, Saint Germain de la Bouexière, &c.), containing *Trinucleus Goldfussi, Calymene Bayani, Orthis redux, O. budleighensis, O. pulvinata, O. valpyana, O. Berthosi, Nucleospira Vicaryi, Lingula Morierei, Pseudarca typa, Diplograptus foliaceus, D. angustifolius*.
		Slates of La Couyère (*Orthis Berthosi*).
		Nodular shales of Guichen, &c. (*Calymene Tristani, Placoparia Tourneminei, Acidaspis Buchii*).
		Slates of Angers (*Ogygia Desmaresti, Didymograptus Murchisoni, D. euodus, D. nanus, D. furcillatus*).
		Shales of Laillé and Sion (*Placoparia Zippei, Asaphus Guettardi, Hyolithes cinctus*, and *Dictyograptus*).
	Arenig.	Armorican sandstone (Grès Armoricain),[2] containing *Scolithes, Bilobites, Asaphus armoricanus, Lingula Lesueuri, L. Hawkeii, L. Salteri, Dinobolus Brimonti, Lyrodesma armoricana, Actinodonta, Ctenodonta, Redonia*, &c.
		Red shales and conglomerates without fossils.

An interesting series of diabase-lavas and tuffs is interstratified in the Middle and Upper Silurian series of the west of Brittany.[3]

In Normandy, where the first French graptolites were found, some of the species characteristic of the uppermost groups of Brittany have been obtained. Silurian fossils have also been detected southwards in Maine and Anjou, and still more abundantly from the ridge of old rocks which forms the high grounds of Languedoc, where the following section has been determined.[4]

> Shales and ampelitic orthoceratite limestones (200 metres) in two stages, the upper of which contains *Monograptus bohemicus, M. colonus, M. Roemeri, M. Nilssoni*, and represents the Ludlow rocks; while the lower, with *Arethusina Koninckii, Monograptus priodon*, var. *Flemingii*, is equivalent to the Wenlock group.
>
> Alternations of shales and white cystidean limestones.

[1] Barrois, *Ann. Soc. Géol. Nord*, xxvii. (1898), pp. 178, 212.

[2] For the fauna of this important rock see Barrois, *Ann. Soc. Géol. Nord*, xix. (1891), pp. 134-237.

[3] Barrois, *Bull. Cart. Géol. France*, No. 7, 1889.

[4] Rouville, 'Monographie Géol. de Cabrières, Herault' (1887). Bergeron ('Étude Géol. du Massif ancien au sud du Plateau Central' (1889). Barrois (*Ann. Soc. Géol. Nord*, xx. (1892), pp. 75-193) discusses fully the distribution of graptolites in the Silurian districts of France. F. Frech, *Zeitsch. Deutsch. Geol. Ges.* (1887), p. 360.

Shales with *Orthis Actoniæ.*

Green shales with concretions (gâteaux) formed around large trilobites, *Asaphus Fourneti, Illænus Lebescontei, Didymograptus euodus.* These strata are probably of Llandeilo age.

Sandstone and grit like the Grès Armoricain, about 50 metres thick, containing *Cruziana, Vexillum, Lingula Lesueuri, Dinobolus Brimonti.*

Shales with calcareous nodules (150 metres) containing *Bellerophon Oehlerti, Agnostus, Calymene, Illænus, Megalaspis, Didymograptus balticus, D. pennatulus, D. nitidus, D. bifidus, D. indentus, Tetragraptus serra, T. quadribrachiatus.* These strata and the overlying sandstone represent the British Arenig rocks.

Researches in the Pyrenees have revealed representatives of the Lower and Upper Silurian formations. The Lower division contains in its upper part a characteristic assemblage of Caradoc fossils, while the Upper includes a large series of strata, which from their graptolites may be paralleled with the English and Scottish Ludlow, Wenlock, and Tarannon groups.[1] Three zones with *Monograptus vomerinus, M. Becki,* and *M. crassus* are well developed, and are compared by Dr. Barrois with the British zones of *Rastrites maximus, Monograptus exiguus,* and *Cyrtograptus Grayæ* respectively. The same observer remarks that these graptolitic faunas of the Pyrenees present more resemblance to others found in the south of Europe than to those in the original typical regions of Britain and Scandinavia. The specific types are generally the same as those of Bohemia.[2] Silurian rocks have been recognised at various points on the Iberian tableland, a lower quartzite, with *Cruziana, Lingula,* &c., being surmounted by shales containing *Calymene Tristani,* &c. Graptolite-bearing schists occur in the province of Minho in the west of Portugal.[3] In the north-east of Spain the several formations of the Upper Silurian series have now been determined by means of their graptolites to be developed in Catalonia: (1) the white shales of Can Ferrés representing the Llandovery group; (2) the black ampelitic and pyritous shales of Camprodon, the Tarannon; (3) the ampelites of Gracia and Santa-Cren de Olorde, the Wenlock; and (4) the black shales of Cervello, the Ludlow.[4]

Central and Southern Europe.—Reference has already been made to the remarkable fact in the Palæozoic geology of the European continent that while the general facies of the fossils continues tolerably uniform in the north-west and north throughout the Silurian territory first described, that is, from Ireland across the Baltic basin into Russia, a great contrast is to be noted between this northern facies and that of central and southern Europe. It is in Bohemia that this contrast is most strikingly presented. Out of the many thousands of species obtained in that country very few are found also in the north. Among the forms common to the two regions graptolites are especially prominent, more than a dozen of the characteristic Upper Silurian species of Britain being also found in the southern province.[5]

In the important Silurian basin of Bohemia,[6] so admirably worked out by Barrande, the formations were grouped by him as in the subjoined table:—

[1] Caralp, 'Études géol. sur les hauts Massifs des Pyrénées centrales,' Toulouse, 1888, p. 453. J. Roussel, 'Etude Stratigraphique des Pyrénées,' *Bull. Carte. Géol. France,* No. 35 (1893).

[2] Barrois, *Ann. Soc. Géol. Nord* (1892), p. 127. On the Silurian rocks of the Asturias see Barrois, *Mém. Soc. Géol. Nord,* 1882.

[3] J. F. N. Delgado, *Comm. Trabal. Geol. Portugal,* II. fasc. ii. (1892).

[4] Barrois, *B. S. G. F.* xxvi. (1898), p. 829; i. (1901), p. 637; *Ann. Soc. Géol. Nord.* xix. p. 63; xx. p. 61; xxvii. (1898), p. 180.

[5] Marr, *Q. J. G. S.* 1880, p. 603.

[6] See Barrande's magnificent work, 'Système Silurien de la Bohème.' F. Katzer, 'Geologie von Böhmen,' 1892, p. 791. J. E. Marr, *Q. J. G. S.* 1880, p. 591. F. Frech, *Neues Jahrb.* ii. (1899), p. 164. J. J. Jahn, *Jahrb. K. K. Geol. Reichsanst* 1898, p. 207.

Upper Silurian.	3rd Fauna.	Stage H.[1]	Shales with coaly layers and beds of quartzite (*Phacops fecundus, Tentaculites elegans*), with species of *Leptæna, Orthoceras, Lituites, Goniatites*, &c.	850 ft.
		,, G.	Argillaceous limestones with chert, shales, and calcareous nodules. Numerous trilobites of the genera *Dalmanites, Bronteus, Phacops, Proëtus, Harpes*, and *Calymene; Atrypa reticularis, Pentamerus linguifer.*	1000 ,,
		,, F.	Pale and dark limestone with chert. *Harpes, Lichas, Phacops, Atrypa reticularis, Pentamerus galeatus, Favosites gotlandica, F. fibrosa, Tentaculites.*	
		,, E.	Shales with calcareous nodules, and shales resting on sheets of igneous rock (300 ft.), lying with a slight unconformability on the group below. A very rich Upper Silurian fauna, abundant cephalopods, trilobites, *Halysites catenularia*, graptolites in many species, such as are found in the Birkhill group of Britain.	450–900 ,,
Lower Silurian.	2nd Fauna.	,, D.	Yellow, grey, and black shales, with quartzite and conglomerate at base, divided by Barrande into five bands numbered D*d*1 to D*d*5, the first being further separated into three members D*d*1 α, β and γ. D*d*1 α and β may perhaps be paralleled with the Welsh Tremadoc group, D*d*1 γ with the Arenig rocks, D*d* 2, 3, 4, and 5 with the Bala-Caradoc rocks. Abundant trilobites of genera *Trinucleus, Ogygia, Asaphus, Illænus, Remopleurides*, &c.	3000 ,,
Cambrian.	Primordial Fauna.	,, C.	Shales, sometimes with porphyries and conglomerates. *Paradoxides, Ellipsocephalus, Agnostus, Arionellus*, and other genera of trilobites referred to above (*ante*, p. 928).	300 ,,
		,, B.	Grits, shales, and conglomerates.	
Pre-Cambrian.		,, A.	Green schists, grits, breccias, tuffs, and hornstones resting on gneiss.	

Small though the area of the Silurian basin of Bohemia is (for it measures only 100 miles in extreme length by 44 miles in its greatest breadth), it has proved extraordinarily rich in organic remains. Barrande has named and described several thousand species from that basin alone, the greater number being peculiar to it. Some aspects of its organic facies are truly remarkable. One of these is the extraordinary variety and abundance of its straight and curved cephalopods, of which 18 genera and two sub-genera, comprising in all no fewer than 1127 distinct species, were determined by Barrande. The genus *Orthoceras* alone contained in his census 554 species, and *Cyrtoceras* had 330.[2] Of the trilobites, which appear in great numbers and in every stage of growth, as many as 42 distinct genera were noted, comprising 350 species; the most prolific genus being *Bronteus*, which included 46 species entirely confined to the *3rd* fauna or Upper Silurian. *Acidaspis* had 40 species, of which six occur in the *2nd*

[1] Stages H, G, and the greater part of F are now more appropriately classed as Devonian (pp. 981, 993). Kayser, *Z. D. G. G.* xxix. (1877), pp. 207, 629, noticed the occurrence of Bohemian "Upper Silurian" fossils in the Rhenish Lower Devonian rocks; see also *Neues Jahrb.* 1884, p. 81, and his conjoint papers with Holzapfel in *Jahrb. Preuss. Geol. Landesanst*, xiv. (1893), p. 236, and *Jahrb. K. K. Geol. Reichanst.* xliv. (1894), p. 479. Barrande defended his classification: *Verh. K. Geol. Reichs.* 1878, p. 200.

[2] 'Syst. Silur.' ii. suppt. p. 266, 1877.

and 34 in the *3rd* fauna. *Proëtus* also numbered 40 species, which all belong to the *3rd* fauna, save two found in the *2nd*. Other less prolific but still abundant genera are *Dalmanites*, *Phacops*, and *Illænus*. The *2nd* fauna, or Lower Silurian series, was found by Barrande to contain in all 32 genera and 127 species of trilobites; while the *3rd* fauna, or Upper Silurian series, contained 17 genera and 205 species, so that generic types are more abundant in the earlier and specific varieties in the later rocks.[1]

Reference may be made here to the famous doctrine of "Colonies" propounded and ably defended by the illustrious Barrande. Drawing his facts from the Bohemian basin, he believed that while the Silurian strata of that region presented a normal succession of organic remains, there were nevertheless exceptional bands, which containing the fossils of a higher zone, were yet included on different horizons among inferior portions of the series. He termed these precursory bands "colonies," and defined the phenomena as consisting in the partial co-existence of two general faunas, which, considered as a whole, were nevertheless successive. He supposed that, during the later stages of his second Silurian fauna in Bohemia, the first phases of the third fauna had already appeared, and attained some degree of development, in a neighbouring but yet unknown region. At intervals, corresponding doubtless to geographical changes, such as movements of subsidence or elevation, volcanic eruptions, &c., communication was opened between that outer region and the basin of Bohemia. During these intervals a greater or less number of immigrants succeeded in making their way into the Bohemian area, but as the conditions for their prolonged continuance there were not yet favourable, they soon died out, and the normal fauna of the region resumed its occupancy. The deposits formed during these partial interruptions, notably graptolitic schists and calcareous bands, accompanied by igneous sheets, contain, besides the invading species, remains of some of the indigenous forms. Eventually, however, on the final extinction of the second fauna, and, we may suppose, on the ultimate demolition of the physical barriers hitherto only occasionally and temporarily broken, the third fauna, which had already sent successive colonies into the Bohemian area, now swarmed into it, and peopled it till the close of the Silurian period.[2]

The general verdict of palæontologists has been adverse to this original and ingenious doctrine. The apparent intercalation of younger zones in older groups of rock has been accounted for by such infoldings of strata as have already been described in this volume and by the effects of faults. It has been shown that not only are the zones repeated, but that when they reappear they bring with them their minute palæontological subdivisions and their peculiar lithological characters.[3]

Silurian rocks appear in a few detached areas in Germany, but the only comparatively large tract of them occurs in Thuringia and the Fichtelgebirge. They present a great contrast to those of Bohemia in their comparatively unfossiliferous character. In the Thüringer Wald, a series of fucoidal-slates (Cambrian, p. 928) passes up into slates, greywackes, &c. (Griffelschiefer, Lederschiefer), with *Conularia*, *Orthis*, *Asaphus*, *Ogygia*, and other fossils. These strata (from 1600 to 2000 feet thick) may represent the Lower Silurian groups. They are covered by some graptolitic alum-slates, shales, flinty slates, and limestones (*Favosites gotlandica*, *Cardiola interrupta*, *Tentaculites acuarius*, &c.), which no doubt represent the Upper Silurian groups, and pass into the base of the Devonian system.[4] The graptolites include many species found in the Stockdale shales of the Lake District, so that the Llandovery group is well represented in this part of the

[1] *Op. cit.* i. suppt. "Trilobites," 1871.

[2] The doctrine of colonies is developed in the 'Système Silurien du Centre de la Bohème,' i. (1852), p. 73; 'Colonies dans le Bassin Silurien de la Bohème,' in *B. S. G. F.* (2nd ser.) xvii. (1859), p. 602; 'Défense des Colonies,' Prague, i. (1861), ii. 1862, iii. (1865), iv. (1870), v. (1881).

[3] J. E. Marr, *Q. J. G. S.* 1880, p. 605; 1882, p. 313.

[4] Richter, *Z. D. G. G.* xxi. p. 359; xxvii. p. 261.

continent.[1] In the Harz, the Tanne greywacke, containing land-plants (p. 937), is overlain by siliceous shales, cherts, and quartzite, above which come graptolitic shales with Monograptidæ and *Cardiola interrupta*.[2] Farther east, in Russian Poland, representatives of both divisions of the Silurian system have been found. The Lower (Bukowka Sandstone) in the Kielce district has afforded a few species of brachiopods (*Orthis calligramma, O. obtusa, O. moneta, Orthisina plana*), while the Upper, which is better developed, has furnished a large series of distinctive fossils (*Monograptus priodon, M. leptotheca, M. bohemicus, M. colonus, M. scanicus, Climacograptus scalaris, Cardiola interrupta, Orthoceras gregarium*, &c.). The higher parts of the series, which may belong to the horizon of the Ludlow rocks, contain among other fossils *Beyrichia Kloedeni, Spirifer elevatus, Atrypa reticularis, Rhynchonella (Camarotœchia?) nucula*.[3]

In the south-west of Russia (Podolia) and in Gallicia, an Upper Silurian area occurs in which there is almost perfect palæontological agreement with the Silurian rocks of the basin of the Baltic, but a great contrast to those of Bohemia, with which it has only a few brachiopods in common.[4]

Among the Alps, the band of ancient sedimentary rocks which, flanking the crystalline masses of the central chain, has been termed the "greywacke zone," has in recent years been ascertained to contain representatives of the Silurian, Devonian, Carboniferous, and Permian systems.[5] In the eastern Alps, a belt of clay-slate and greywacke, with limestone, dolomite, magnesite, ankerite, and siderite runs from Kitzbühel in the Tyrol as far as the south end of the Vienna basin. About twenty species of fossils (*Orthoceras, Atrypa, Cardiola*, &c.) found at Dienten, near Werfen, belong apparently to the substage *e*2 of Barrande's Stage E. In this band, the strata have been changed into crystalline schists. As the fossils are Upper Silurian, a large part of the adjacent unfossiliferous schistose rocks may represent older parts of the Silurian system; but no Lower Silurian fossils have yet been found in them in the northern Alps.

In the southern Alps (Carinthia), above the older Palæozoic masses which have not yet yielded fossils, the following subdivisions have been given by Stache in descending order:—

Limestones (1000 to 1500 feet) with Silurian forms of *Pentamerus, Spirifer, Rynchonella*, and *Atrypa*, and Silurian and Devonian corals = Stages F, G, H of Barrande.

Dark clay-slates and sandstones with plant-remains, yellow and red crinoid-shales = Stage F, in parts Onondago group (?).

Limestone with orthoceratites, gasteropods, lamellibranchs, trilobites (Kokberg). About 100 species occur in the lower or dark Orthoceras limestone. These rocks appear to represent Stage E of Bohemia, and the Ludlow and Wenlock groups of England.

Graptolite-schists with *Petalograptus folium, D. pristis*, &c. = Stage D and base of E (Tarannon group).

Greywacke-slate and sandstone (*Strophomena grandis, Orthis*) = upper part of Stage D; perhaps Bala beds.[6]

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1 Marr, *Geol. Mag.* 1889, p. 414. Tornquist, *Geol. Fören. Stockholm*, ix. (1887).

2 Lossen, *Z. D. G. G.* xx. p. 216; xxii. p. 284; xxix. p. 612.

3 G. Gürich, *Verh. Russ. Min. Gesellsch.* 2nd ser., xxxii. (1896), p. 19.

4 F. Schmidt, 'Die Podolisch-galizische Silurformation,' St. Petersburg, 8vo, 1875.

5 Von Hauer, 'Geologie,' p. 216. Stache, *Jahrb. Geol. Reichs.* xxiii. p. 175; xxiv. pp. 136, 334; *Verh. Geol. Reichs.* 1879, p. 216. Stache divided the greywacke zone of the eastern Alps into five pre-Triassic groups: 1, Quartzphyllite group; 2, Kalkphyllite group; 3. Kalkthonphyllite group; 4, Group of the older greywackes (Silurian and Devonian); 5, Group of the Upper Coal and Permian rocks.

6 *Verhandl. Geol. Reichs.* 1884, p. 25; *Z. D. G. G.* 1884, p. 277.

In the southern half of Sardinia, Silurian rocks (in part, at least, Upper) have been divided into three zones, the lowest of which contains important metalliferous lodes.[1] Among these rocks Meneghini recognises two chief graptolitic horizons, one probably representing the Tarannon sub-group (with *Monograptus antennularius*, comp. *Becki*, *M. Gonii*, comp. *continens*, *M. hemipristis*, comp. *jaculum*) the other (with *M. colonus*, *M. Lamarmoræ*, *M. multuliferus*, comp. *vomerinus*) answering to the Wenlock group.

North America.[2]—In the United States and Canada, Silurian rocks spread continuously over a vast territory, from the mouth of the St. Lawrence south-westwards into Alabama and westwards by the great lakes. They almost encircle and certainly underlie all the later Palæozoic deposits of the great interior basin. The rocks are most typically developed in the State of New York, where they have been arranged as in the subjoined table:—

Upper.

(5) Lower Helderberg group[3] consisting of
- (*c*) Upper Pentamerus limestone (*Pentamerus pseudo-galeatus*).
- (*b*) Delthyris limestone (*Meristella lævis*).
- (*a*) Lower Pentamerus limestone (*Pentamerus galeatus*).

(4) Water-lime (*Tentaculites*, *Eurypterus*, and *Pterygotus*) Onondago salt group, consisting of red and grey marls, sandstones, and gypsum, with large impregnation of common salt, but nearly barren of fossils. The Guelph formation, however, with its pale dolomites, has yielded a large series of fossils which have been worked out by Hall, Billings, and Whiteaves.

(3) Niagara shale and limestone; *Halysites*, *Favosites*, *Calymene Blumenbachii*, *Homalonotus delphinocephalus*, *Plectambonites* (*Leptæna*) *transversalis*, *Dendrograptus* (7 species), *Callograptus* (4), *Dictyonema*, *Calyptograptus*, *Inocaulis*, &c.; also fish-remains (*Onchus*, *Glyptaspis*) in the shale in Pennsylvania. The Niagara Limestone may be paralleled with the Wenlock Limestone.

(2) Clinton group (*Pentamerus oblongus*, *Atrypa reticularis*, *Monograptus clintonensis*, *Retiolites venosus*, &c.). This group may represent the Tarannon shales.

(1) Medina group with Oneida conglomerate (*Modiolopsis orthonota*).

In Nova Scotia and New Brunswick Upper Silurian formations of different aspect from those above enumerated are extensively developed. Several thousand feet of sandstones, slates, iron-ores, black graptolitic slates, limestones, and mudstones have yielded a characteristic fauna resembling that of the typical English districts.

(5) Cincinnati (Lorraine, Hudson River)[4] group (*Syringopora*, *Halysites*, *Pterinea demissa*, *Plectambonites* (*Leptæna*) *sericea*, *Climacograptus bicornis*, *C. typicalis*, *Diplograptus pristis*, *D. putillus*). This group corresponds to the Caradoc rocks of Britain.

(4) Utica group—Utica shale (*Leptograptus flaccidus*, *Diplograptus mucronatus*(?), *D. quadrimucronatus*, *Orthograptus quadrimucronatus*, *Dendrograptus simplex*, *Endoceras proteiforme*, *Orthoceras lamellosum*, *Triarthrus Becki*).

[1] Meneghini, *Mem. Acad. Lincei*, 1880. J. G. Bornemann, 'Die Versteinerungen des Cambrischen Schichtensystems der Insel Sardinien,' Halle, 1886. S. Traverso, *Atti. Soc. Ligust. Sci. Nat.* iii. 1892.

[2] See *Memoirs of the Geological Survey of Canada*, and the publications of the United States *Geol. Surv.*; numerous monographs of the late James Hall, of Albany; Walcott, *Monogr. U.S. G. S.* viii. (1884). The graptolites have been tabulated by R. R. Gurley, *Journ. Geol.* iv. (1896), pp. 63-102; 291-311.

[3] This group is by many geologists placed in the Devonian system, and a considerable amount of controversy has arisen on the subject. It is inserted here according to the classification of Professor H. S. Williams of Yale University, who would draw the line between the Silurian and Devonian system about the middle of the Oriskany group. On this subject see his papers, *Amer. Journ. Sci.* ix. (1900), p. 203; *Bull. Geol. Soc. Amer.* xi. (1900), p. 333; also C. Schuchert, *op. cit.* xi. p. 241, and other papers cited *postea*, p. 997.

[4] On this group see C. D. Walcott, *Bull. Geol. Soc. Amer.* i. (1890), p. 335.

Lower.

(3) Trenton group. — Trenton limestone.[1] Black River limestone. Birdseye limestone. — *Trinucleus concentricus, Illænus americanus, I. crassicauda, Leperditia fabulites, Orthis (Dalmanella) testudinaria, O. (Dalmanella) subæquata, Leptæna (Plectambonites) sericea, Rafinesquina alternata, Murchisonia, Conularia, Orthoceras, Cyrtoceras tenuistriatus, Didymograptus* (7 species) *Climatograptus, Nemagraptus, Leptograptus, Dicellograptus* (10), *Dicranograptus* (12), *Climacograptus* (11), *Diplograptus* (13), *Cryptograptus, Lasiograptus, Glossograptus, Reteograptus, Clathrograptus, Dendrograptus, Dictyonema, Thamnograptus, Phycograptus,* &c.[2]

(2) Chazy group—Chazy limestone (*Maclurea magna, M. Logani, Orthoceras, Illænus, Asaphus, Didymograptus, Climacograptus, Cryptograptus, Glossograptus*).

(1) Calciferous group (*Lingulella acuminata, Leptæna, Conocardium, Ophileta compacta, Orthoceras primigenium, Amphion, Bathyurus, Asaphus, Conocoryphe, Dichograptus, Tetragraptus, Phyllograptus, Didymograptus, Diplograptus, Callograptus, Dictyonema, Caryocaris,* &c.). This group answers to the Welsh Arenig rocks.[3]

The number of genera and even of species common to the Silurian rocks of America and Europe, and the close parallelism in their order of appearance indicate a former migration along shallow northern waters between the two continents. Among these common species the following may be enumerated as occurring in the Upper Silurian rocks of New York, the coasts of Barrow Straits within the Arctic Circle, Britain, and the Baltic basin: *Stromatopora concentrica, Halysites catenularia, Favosites gotlandica, Orthis elegantula, Atrypa reticularis.* The genera of graptolites appear to have followed the same order of appearance and to have reached their full development and final decline at corresponding stages of the Silurian period on each side of the Atlantic. Among the crustacea, trilobites were the dominant order, represented in each region by a similar succession of genera, and even to some extent of species. And as these earlier forms of articulates waned, there appeared among them about the same epoch in the geological series, the eurypterids of the Water-lime of New York and of the Ludlow rocks of Shropshire and Lanarkshire.

South America.—Lower Silurian fossils have been obtained from Bolivia, Peru, and Argentina, so that the Silurian system has a wide extension in the central and southern parts of the continent. Some of the rocks correspond to the Arenig or Llandeilo formations of Europe, for they contain *Asaphus*(?), *Bathyurus, Ampyx, Megalaspis, Illænus,*

[1] The Trenton limestone contains the zones of (*a*) *Monticuliporidæ*, with *Isotelus gigas, Calymene senaria, Holopea symmetrica,* &c.; (*b*) *Parastrophia hemiplicata*, with *Ctenodonta levata,* &c.; (*c*) *Plectambonites sericeus* exclusively; (*d*) *Orthis* (*Dalmanella*) *testudinaria* crowded together, also with *Calymene senaria, Rafinesquina alternata,* &c.; (*e*) *Isotelus gigas* and *Lingula curta*, with *Diplograptas amplexicaulis, Orthoceras vertebrate,* &c. T. G. White, *Report of Director, New York State Museum,* Appendix A; *Bull. Geol. Soc. Amer.* x. (1898), p. 452.

[2] Remains of ganoid fishes, like *Holoptychius* and *Asterolepis*, and of a chimæroid fish, have been found in what seems to be a representative of the Trenton group in Colorado. C. D. Walcott, *Bull. Geol. Soc. Amer.* iii. (1892), p. 153.

[3] According to researches by Mr. Selwyn, the so-called Quebec group as defined by Logan embraces three totally distinct groups of rock, belonging respectively to Archæan, Cambrian, and Lower Silurian horizons; and in the fossiliferous belt of Logan's Quebec group are included, in a folded, crumpled, and faulted condition, portions of subdivisions that lie elsewhere comparatively undisturbed, and embrace strata even lower than the Potsdam formation. *Trans. Roy. Soc. Canada,* vol. i. sect. iv. p. 1 (1882).

Lituites, Maclurea, Orthis calligramma, and the characteristic *Didymograptus Murchisoni.* A Caradoc horizon may perhaps be marked by strata containing a graptolite closely related to *Diplograptus truncatus,* while Upper Silurian fossils have been recorded from Pará, Brazil, whence species of *Lingula, Orthis, Chonetes, Anabaia, Anodontopsis, Murchisonia, Conularia, Orthoceras, Cyrtoceras, Primitia,* and *Bollia* have been obtained.[1]

Asia.—Silurian rocks extend into the heart of this continent, thence eastwards to China and southwards into India. In Turkestan strata have been found containing *Homalonotus bisulcatus, Leperditia Schmidtii, Pleurotomaria microstriata* and *Leptodomus truncatus.*[2]

From the province of Sze Chuen, in Western China, Richthofen obtained numerous fossils which show the presence there of Middle and Upper Silurian rocks. Among the species, some are the same as those that occur in Western Europe, such as *Orthis calligramma, Plectambonites (Leptæna) sericea, Spirifer radiatus, Atrypa reticularis, Favosites fibrosa, Heliolites interstinctus, Halysites catenularia,* and others.[3]

The Salt Range of the Punjab contains thick masses of bright red marl, with beds of rock-salt, gypsum, and dolomite, over which lie purple sandstones and shales. These saliferous rocks have been already (p. 933) referred to as containing Cambrian fossils, but it is not yet known whether they include any representatives of the Silurian system.[4] In the regions of the Northern Punjab and Kashmir traces of Silurian organic remains have been discovered; while in the north of Kumaun such fossils have been found in considerable quantities. In the central Himalayas of Hundes and Spiti a series of conglomerates, quartzites, phyllites, slates, and shales from 3000 to 4000 feet thick, the age of which does not appear to have been precisely determined, passes upward into a group of strata, 1200 feet or more in thickness, which is assigned to the Silurian system. It consists in great part of coral-limestone and has furnished a large number of fossils, including species of *Sphærexochus, Lichas, Calymene, Illænus, Cheirurus,* &c.[5]

Australasia.—In Australia, Tasmania, and New Zealand the existence of the Silurian system has been proved by the discovery of a considerable number of characteristic fossils. In Victoria both Lower and Upper Silurian fossils have long been known to exist in a thick series of sedimentary deposits, the older portions of which, perhaps including Cambrian and even pre-Cambrian rocks, have been altered into crystalline schists.[6] The Lower Silurian strata, consisting of sandstones, slates, shales, mudstones, conglomerates, and breccias have yielded a considerable number of graptolites which, as usual, are crowded together in the black shales. By means of these fossils the rocks have been separated into graptolitic zones, which may be broadly paralleled with those of Europe. In the shales of Lancefield the oldest group of fossils includes species of *Bryograptus, Leptograptus, Didymograptus, Tetragraptus, Clonograptus;* apparently above these lie the graptolites of Castlemaine, of which the lowest zone is distinguished by the abundance of *Tetragraptus fruticosus,* associated with *T. quadribrachiatus, T. serra (bryonoides), Dichograptus,* sp. *Phyllograptus typus, Goniograptus, Thamnograptus typus, Didymograptus caduceus.* The next zone in ascending order is marked by

[1] D. Forbes, *Q. J. G. S.* xvii. (1861), p. 53. Kayser, *Z. D. G. G.* xlix. (1897), p. 274; l. (1898), p. 423. E. T. Newton, *Geol. Mag.* 1901, p. 195. J. M. Clarke, *Archiv. Mus. Nac. Rio de Janeiro,* x. (1899).

[2] G. Romanowski, 'Materialen zur Geologie von Turkestan,' 1 Lief. St. Petersburg, 1880, p. 39.

[3] Richthofen's 'China,' vol. iv. pp. 37, 50, where descriptions of the fossils are given by Kayser and Lindström.

[4] A. B. Wynne, *Mem. Geol. Surv. India,* xiv. See also *Palæont. Indica.* ser. 13, vol. i. (1887), p. 750; Medlicott and Blanford, 'Manual of the Geology of India,' 1879, p. xxv.

[5] Medlicott and Blanford, *op. cit.* p. 649, and 2nd ed. by R. D. Oldham, p. 115.

[6] R. A. F. Murray, 'Geology and Physical Geography of Victoria,' Melbourne, 1887, p. 33.

the abundance of *Didymograptus bifidus;* the third by the profusion of *Phyllograptus typus* and *Didymograptus caduceus,* while higher up *Loganograptus Logani* is the prominent species.[1] Upper Silurian formations, said to extend over a considerable area of the colony, consist of sandstones, mudstones, shales, and slates with crinoidal and coral limestones. They have yielded an abundant series of fossils, including corals, star-fishes, crinoids, trilobites (*Phacops, Lichas, Homalonotus, Bronteus, Calymene,* &c.).

In the Macdonnell Range of Central South Australia the presence of Lower Silurian rocks is indicated by the discovery there of species of *Asaphus, Orthis, Ophileta, Raphistoma, Murchisonia, Orthoceras,* and *Endoceras.*[2] In New South Wales it is the Upper Silurian formations which have been developed, expanding there, in a succession of shales, limestones, sandstones, grits, and conglomerates, to a thickness of sometimes more than 3000 feet (Yass). From these strata a large suite of organic remains of unmistakable Upper Silurian types has been obtained. They include species of *Alveolites, Cyathophyllum, Favosites, Halysites, Heliolites, Omphyma, Bronteus, Calymene, Cheirurus, Encrinurus, Homalonotus, Proëtus, Leptæna, Pentamerus,* and many more.[3] It is interesting to note among these fossils the world-wide species *Favosites aspera, F. fibrosa, F. gotlandica, Omphyma Murchisoni, Calymene Blumenbachii, Encrinurus punctatus, Proëtus Stokesii, Atrypa reticularis, A. hemispherica, Chonetes striatella, Plectambonites* (*Leptæna*) *sericea, Pentamerus Knightii, P. oblongus,* and others equally familiar.

Tasmania likewise furnishes a good representation of both subdivisions of the Silurian system. The Lower division is grouped by Mr. R. M. Johnston in two sections, the older of which, the Auriferous Slate group, consists of slates and grits with graptolites (*Didymograptus*); the younger, the Gordon River group of limestones and conglomerates, has yielded a varied fauna of corals (*Halysites, Favosites, Syringopora, Phillipsastræa,* &c.), brachiopods, lamellibranchs (*Cyrtodonta*), gasteropods (*Raphistoma,* &c), cephalopods (*Orthoceras, Lituites*), and other organisms. The Upper Silurian formations of the island, classed in the Eldon group and consisting of slates, mudstones, sandstones, conglomerates, and limestones, have supplied many fossils, among which are species of *Pentamerus, Orthis, Strophomena, Calymene,* &c.

In New Zealand a thick mass of sedimentary formations, classed by Captain Hutton as his Tákaka system, has been subdivided into (1) a lower division (Wanaka, including the Mount Arthur and Aorere series of Sir J. Hector) in which a few crinoids, graptolites, and a coral have been found, and which are referred to the Lower Silurian series. They are much disturbed by hornblendic and syenitic eruptive rocks ; and (2) an upper division (Baton River series, including the Kakanui and Waihao series), consisting of slates, sandstones, and limestones, from which *Calymene Blumenbachii, Spirifer radiatus, Stricklandinia lirata,* and other Upper Silurian forms have been procured. A great part of the so-called metamorphic schists are probably Upper Silurian rocks.[4]

Section iii. Devonian and Old Red Sandstone.

In Wales and the adjoining counties of England, where the typical development of the Silurian system was worked out by Murchison, the abundant Silurian marine fauna disappears in the red rocks that overlie the Ludlow group. From that horizon upwards in the geological series

[1] T. S. Hall, *Proc. Roy. Soc. Victoria,* 1894, 1896, 1897, 1898. F. M'Coy, 'Prodromus of the Palæontology of Victoria,' Dec. i. ii. and v.

[2] R. Etheridge, junr. 'Additional Silurian and Mesozoic Fossils from Central Australia,' Adelaide, 1893. De Koninck, 'Foss. Palæoz. Nouvelles Galles du Sud,' 1876.

[3] R. Etheridge, junr. 'A Catalogue of Australian Fossils,' Cambridge, 1878 ; W. B. Clarke, 'Remarks on the Sedimentary Formations of New South Wales,' 4th edit. ; C. S. Wilkinson, 'Notes on the Geology of New South Wales,' Sydney (1882).

[4] F. W. Hutton, *Q. J. G. S.* xli. (1885), p. 198 ; Hector, 'Handbook of New Zealand,' p. 37.

we have to pass through some 10,000 feet or more of barren red sandstones and marls, until we again encounter a copious marine fauna in the Carboniferous Limestone. It is evident that between the disappearance of the Silurian and the arrival of the Carboniferous fauna, very great geographical changes occurred over the site of Wales and the west of England. For a prolonged period, the sea must have been excluded, or at least must have been rendered unfit for the existence and development of marine life, over the area in question. The striking contrast in general facies between the organisms in the Silurian and those in the Carboniferous system, proves how long the interval between them must have been.

The geological records of this interval in Wales and the west of England are still only partially unravelled and interpreted. At present the general belief among geologists is that, while in the west and north of Europe the Silurian sea-bed was upraised into land in such a way as to enclose large inland basins, in the centre and south-west the geographical changes did not suffice to exclude the sea, which continued to cover that region more or less completely. In the isolated basins of the west and north, a peculiar type of deposits, termed the Old Red Sandstone, is believed to have accumulated, while in the shallow seas to the south and east, a series of marine sediments and limestones was formed, to which the name of Devonian has been given. It is thus supposed that the Old Red Sandstone and Devonian rocks represent different geographical areas, with different phases of sedimentation and of life, during the long lapse of time between the Silurian and Carboniferous periods. A somewhat similar contrast between the lithological and palæontological characters of the corresponding formations in different parts of the United States and Canada, shows that in America also this geological period was marked by geological changes which produced distinct geographical conditions in adjacent regions.

That the Old Red Sandstone of Britain does represent the prolonged interval between Silurian and Carboniferous time can be demonstrated by innumerable sections, where the lowest strata of the system are found graduating downward into the top of the Ludlow group, and where its highest beds are seen to pass up into the base of the Carboniferous system. But the evidence is not everywhere so clear in regard to the true position of the Devonian rocks. That these rocks lie between Silurian and Carboniferous formations was long ago shown by Lonsdale from their fossils. But it is a curious fact that in some countries where the Lower Devonian beds are developed, the Upper Silurian are scarcely to be recognised, or, if they occur, can hardly be separated from the so-called Devonian rocks. It is quite possible, therefore, that the lower portions of what has been termed the Devonian series may, in certain regions, to some extent represent what are elsewhere recognised as undoubted Ludlow or even perhaps Wenlock rocks.[1] We cannot suppose that the rich Silurian fauna died out abruptly

[1] According to Kayser and Beyrich the limestones of the Hercynian series in the Harz and Nassau, together with Barrande's Upper Silurian Stages F, G, H, in Bohemia, are to be regarded as truly Devonian, and as being the deeper-water equivalents of the arenaceous series of the normal Lower Devonian series on the Rhine. (*Abhandl. Geol. Specialkarte Preussen*, II. Heft 4, 1878. *Z. D. G. G.* xxxiii. (1881), p. 628.) See *postea*, p. 993.

at the close of the Ludlow epoch. We should be prepared for the discovery of Silurian rocks younger than the latest of those in Britain, such as Barrande showed to exist in his Étage H, or for a Devonian facies of fossils in rocks which are nevertheless regarded as Silurian. The rocks termed Lower Devonian may partly represent some of the later phases of Silurian life. On the other hand, the upper parts of the Devonian system might in several respects be claimed as fairly belonging to the Carboniferous system above.[1]

The marine or Devonian type must be regarded as the more usual and widely extended form of the system. It will therefore be taken first in the following descriptions. The Old Red Sandstone, with its extremely interesting but more local development, will be afterwards discussed.

I. DEVONIAN TYPE.

§ 1. General Characters.

Rocks.—Throughout central and western Europe, the Devonian system presents a remarkable persistence of petrographical characters, indicating probably the prevalence of the same kind of physical conditions over the area during the period when the rocks were accumulated. The lower division consists mainly of sandstones, grits, and greywackes, with slates and phyllites. These rocks attain a great development on the Rhine, where they form the material through which the picturesque gorges of that river have been eroded. In the central zone, limestones predominate, often crowded with the corals and mollusks of the clearer water in which they were laid down, and in some cases actually representing former coral-reefs.[2] The upper series is more variable: being in some tracts composed of sandstones and shales, in others of shales and limestones, but everywhere presenting a more shaly thin-bedded aspect than the subdivisions beneath it. Considerable masses of diabase, tuff (schalstein, p. 175), and other associated volcanic materials are inter-

[1] J. B. Jukes proposed a solution of the English Devonian problem, the effect of which would be to turn the whole of the Devonian rocks into Lower Carboniferous, and to place them above the Old Red Sandstone, which would thus become the sole representative in Europe of the interval between Silurian and Carboniferous time. *Journ. Roy. Geol. Soc. Ireland*, 1865, i. Part. 1, new ser.; *Q. J. G. S.* xxii. 1866, and his pamphlet on 'Additional Notes on Rocks of North Devon,' &c. 1867). The "Devonian question," as it has been called, has evoked a large number of papers, of which, besides those cited in subsequent pages, the following may be enumerated: Professor Hull, *Q. J. G. S.* xxxv. (1879), p. 699; xxxvi. (1880), p. 255. A. Champernowne, *Geol. Mag.* v. 2nd ser. (1878), p. 193; vi. (1879), p. 125; viii. (1881), p. 410. The general verdict has been adverse to the explanation of the structure of North Devon proposed by Jukes, and the position of the Devonian system has now been definitely established on the continent of Europe and in the United States.

[2] Dupont, *Bull. Acad. Roy. Belgique* (3) ii.; *Comptes rend.* Feb. 18, 1884. *Bull. Soc. Belg. Geol.* vi. (1892), *Memoires*, p. 171. The frequent singularly lenticular character of Palæozoic limestones is explicable on the assumption that in many cases they grew up in patches after the manner of modern coral-reefs and shell-banks. The interrupted bands of shale in the Belgian Devonian limestones are regarded by M. Dupont as representing reef-lagoons that were filled up with muddy sediment.

calcated in the Devonian system in Devonshire and in Germany. As a rule, the rocks have been subjected to more or less disturbance, and have in some places been plicated, cleaved, and even metamorphosed into schists, quartzites, &c. In some districts, they have been invaded by large masses of granite and other eruptive rocks.

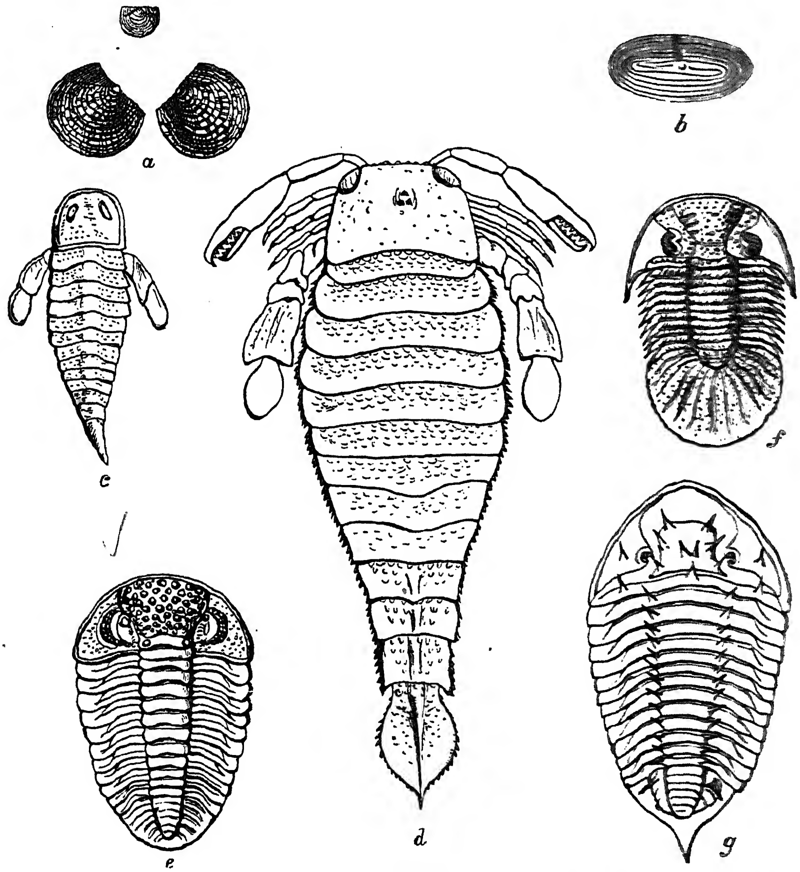

Fig. 384.—Devonian and Old Red Sandstone Arthropoda.

a, Estheria membranacea, Pacht., nat. size and magnified (Lower Old Red Sandstone); *b*, Entomis serrato-striata, Sandb., magnified (Upper Devonian); *c*, Eurypterus pygmaeus, Salt. (Lower Old Red Sandstone); *d*, Pterygotus anglicus, Ag., red. (Lower Old Red Sandstone); *e*, Phacops latifrons, Bronn. (Lower Devonian); *f*, Bronteus flabellifer, Goldf. (Lower Devonian); *g*, Homalonotus armatus, Burm. (Lower Devonian).

Among the economic products, the most important in Europe are the ores of iron, lead, tin, copper, &c., which occur in veins or lenticular masses through the Devonian rocks (Devon and Cornwall, Harz, &c.). In North America the Devonian rocks of Pennsylvania contain bands of "sand-rock" charged with petroleum.

LIFE.—A cryptogamic flora covered the land during the ages that succeeded the Silurian period. As the remains of this vegetation are chiefly preserved in the Old Red Sandstone facies of deposits, it is described at p. 1001. The true Devonian rocks contain remains of marine vegetation (*Chondrites*, *Bythotrephis*), and likewise traces, often badly preserved, of land-plants (*Asterocalamites*, *Archæopteris* or *Palæopteris*, *Psilophyton*, to which the *Haliserites*, formerly thought to be sea-weed, is now referred).

The fauna of the Devonian rocks is unequivocally marine. Among the more lowly forms of animal life are some of which the true zoological grade has been the subject of much uncertainty. Of these, the fossil known as *Calceola sandalina* (Fig. 385) has been successively described as a lamellibranch, a hippurite, and a brachiopod; but is now regarded as a rugose coral possessing an opercular lid like some other members of the cystiphylloid group. The *Pleurodictyum problematicum*, a well-known form of the Lower Devonian beds, is now classed with the Favositidæ among the tabulate corals. The group of Stromatoporoidea, including *Stromatopora*, *Clathrodictyon*, &c., occurs in some of the limestones as abundantly and much in the same way as reef-building corals do in a modern coral-reef. The curious *Receptaculites*, already (p. 937) referred to, is a well-known Devonian fossil, classed by some authors among the calcareous algæ, by others among the foraminifera, or even with the sponges. The Corals of the Devonian seas were both abundant in individuals and varied in their specific and generic range. Not a single species is common either to the Silurian system below or the Carboniferous above. Among the rugose forms, the genera *Cyathophyllum*, *Combophyllum*, *Zaphrentis*, *Phillipsastræa*, *Acervularia*, *Cystiphyllum*, and the already mentioned *Calceola* are characteristic. The tabulate kinds belong chiefly to the important genera of *Favosites*, *Pachypora*, *Trachypora*, *Alveolites*, *Michelinia*, *Pleurodictyum*, *Aulopora*, *Syringopora*, and *Fistulipora*. The Alcyonaria are represented by species of *Heliolites* and *Plasmopora*. Of the Echinoderms by far the most abundant representatives are crinoids, which occur in great profusion in the limestones, sometimes forming entire beds of rock. They belong to the genera *Haplocrinus*, *Cupressocrinus*, *Cylicocrinus*, *Hexacrinus*, *Dorycrinus*, *Rhipidocrinus*, *Melocrinus*, *Calceocrinus*, *Lecythocrinus*, *Ichthyocrinus*, and others. The cystideans are greatly diminished in number, though they linger on into the Carboniferous formations; the Devonian forms belong to the genera *Proteocystis*, *Agelacrinus*, and *Tiaracrinus*. Blastoids, however, are now on the increase, and are represented by species of Pentremitidea, *Nucleocrinus* (*Elæacrinus*), *Codaster*, *Phænoschisma*, &c.; ophiuroids or brittle-stars are likewise present *Eugaster*, *Palæophiura*, *Ophiurina*, *Ophiura*), as well as true star-fishes (*Aspidosoma*, *Palæaster*, *Loriolaster*, *Palasteriscus*) and sea-urchins (*Lepidocentrus*).

The known Crustacean fauna of the Devonian period indicates a striking diminution in number both of individuals and of species of trilobites (Fig. 384). Most of the genera so abundant and characteristic among the Lower Silurian rocks are now absent, but a number of the Upper Silurian genera still remain, only a few new types making their appearance (*Cryphæus*, *Dechenella*). The most frequent Devonian forms

are *Cyphaspis*, *Proëtus*, *Phacops*, *Trimerocephalus*, *Odontochile* (*Dalmanites*), *Homalonotus*, *Bronteus*, *Acidaspis*, *Calymene*, *Harpes*, *Arges* (*Lichas*) and *Cheirurus*. The ostracods are chiefly represented by the genus *Entomis* formerly called *Cypridina*, which occurs in enormous numbers in some Upper Devonian shales ("Cypridinen-schiefer"), but the genera *Leperditia*, *Primitia*, *Klœdinia*, *Beyrichia*, *Bairdia* and *Cypridina* are likewise present. The phyllopods, eurypterids, and myriapods appear chiefly in the Old Red Sandstone, and are noticed on pp. 1003-1006 and Fig. 384.

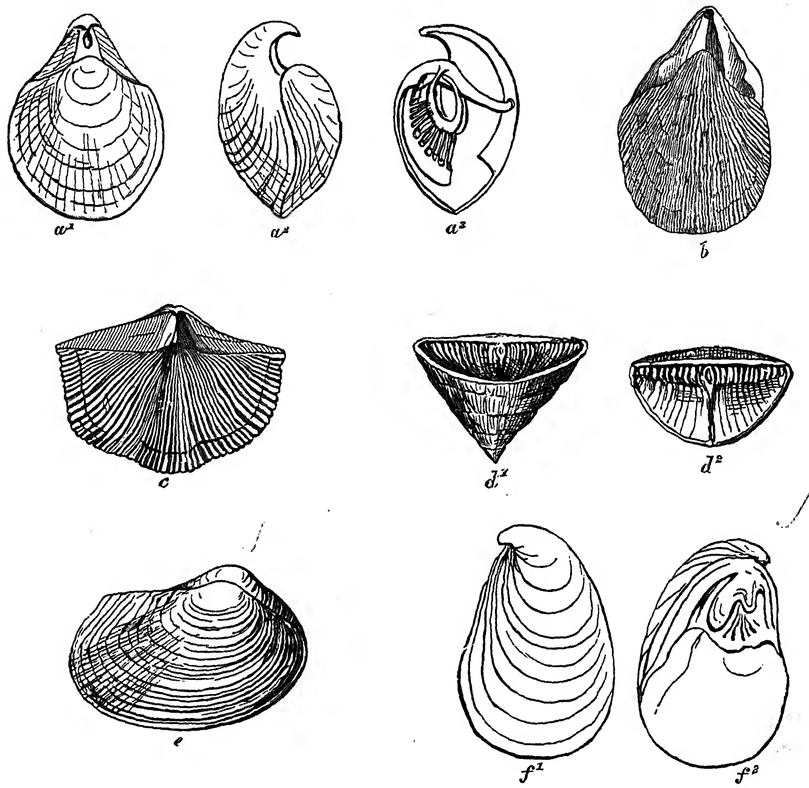

Fig. 385.—Devonian Fossils.

a^1, Stringocephalus Burtini, Def.; a^2, Do. lateral, and a^3, Do. internal view; b, Uncites gryphus, Def.; c, Spirifer Verneuili (disjunctus), Sow.; d^1, Calceola sandalina, Linn.; d^2, Opercular lid of do.; e, Cucullæa unilateralis, Sow. (Hardingii, Sow.); f^1, f^2, Megalodon cucullatus, Sow.

The Brachiopods (Fig. 385) had now reached a remarkable development, whether as regards individual abundance or number of specific and generic forms; more than 60 genera and 1100 species having been described. They compose three-fourths of the known Devonian fauna. Most of the inarticulate forms continue to diminish in number, being represented by species belonging to the still living genus *Lingula* and to *Crania*, *Orbiculoidea*, *Lindstrœmella*, and a few other genera. Of the

articulate types the most abundant are spiriferids, including the genera *Spirifer* (especially broad-winged species), *Uncites*, *Cyrtia*, *Ambocœlia*, *Verneuilia*, and *Metaplasia*. The genus *Atrypa* still continues in its ancient and world-wide species *A. reticularis*. The athyrids are especially prominent, some of their genera being *Retzia*, *Anoplotheca*, *Vitulina*, *Athyris*, *Kayseria*, *Meristella*, *Merista* and *Camarospira*. The rhynchonellids include the genera *Hypothyris*, *Eatonia*, *Pugnax*, *Uncinulus*, *Wilsonia*, and others. The pentamerids continue, but in decreased numbers (*Pentamerella*, *Gypidula*, *Amphigenia*, *Camarophoria*). The orthids are likewise greatly on the wane, but continue even into the Permian system. The productids, on the other hand, show an increase in number and variety, some of their more characteristic genera being *Productella*, *Strophalosia*, *Chonostrophia*, *Anoplia*, and *Chonetes*. The strophomenids, which range from the Lower Silurian into the Permian formations, are represented in the Devonian system by species of *Kayserella*, *Leptæna*, *Pholidostrophia*, and *Stropheodonta*. The terebratulids make their appearance in this system, where one of their most characteristic genera is *Stringocephalus*, one of the largest and most typically Devonian brachiopods (Fig. 385), other forms being *Megalanteris*, *Cryptonella*, *Dielasma*, *Eunella*, and *Tropidoleptus*, to which may be added the characteristic Lower Devonian *Rensselæria*, together with *Centronella*, *Oriskania*, *Trigeria*, and other forms.

Among the Mollusca of the Devonian rocks remains of the pteropod *Tentaculites* are sometimes profusely abundant in the limestones. The known Devonian lamellibranchs belong chiefly to the genera *Pterinea*, *Actinodesma*, *Leptodesma*, *Pteria* (*Avicula*), *Cardiola*, *Megalodon*, *Grammysia*, *Cucullæa*, *Modiomorpha*, *Pleurophorus*, *Cypricardella*, *Curtonotus* and *Aviculopecten*; *Pterinea* being specially abundant in the lower, *Cucullæa* and *Curtonotus* in the upper subdivision of the system. Important genera of gasteropods are *Euomphalus*, *Straparollus*, *Murchisonia*, *Loxonema*, *Macrocheilus*, *Scoliostoma*, *Capulus*, *Pleurotomaria*, *Bellerophon*, and *Porcellia*.

The cephalopods show a marked advance on those of the older periods. Among the nautiloids a number of the older families still survive, including such genera as *Orthoceras*, *Cycloceras*, *Kionoceras*, *Sphyradoceras*, *Loxoceras*, *Actinoceras*, *Cyrtoceras*, and *Poterioceras*. But new forms make their appearance (*Homaloceras*, *Halloceras*, *Ryticeras*, *Rhadinoceras*, *Centroceras*). The ammonoids now take their place at the head of the mollusks, and from this system onward into the Jurassic formations show a constant increase in numbers and variety. In the Devonian rocks they appear in their primitive forms, the clymenioids being more especially typical of these strata. The old genus *Clymenia*, now subdivided into a number of genera, is especially prevalent in the limestones and shales of the upper part of the system. The goniatitoids make their entry in the genera *Bactrites*, *Mimoceras*, *Anarcestes*, *Agoniatites*, *Aphyllites*, *Pinnacites*, *Gephyroceras*, *Timanites*, *Tornoceras*, *Brancoceras*, *Beloceras*, and others. The Devonian cephalopods have been recently employed for the zonal subdivision of the system.[1]

[1] Haug, *Mem. Soc. Géol. France, Paléontol.* 1898. The invertebrate fauna of the Rhine, &c., is described by Kayser and others. See table and authorities cited, pp. 991-995.

The fish fauna of Devonian time has been best preserved among the deposits of the Old Red Sandstone (p. 1004). It would appear that some of the fishes of the inland waters could make their way into the opener seas, where they mingled with marine organisms. In the Devonian rocks of Central Europe scanty remains of these fishes have been found, more especially in the Eifel, but not always in such a state of preservation as to warrant their being assigned to any definite place in the zoological scale. Professor Beyrich described from Gerolstein in the Eifel an undoubted species of *Pterichthys*, which, as it could not be certainly identified with any known form, he named *P. rhenanus*. A *Coccosteus* has been described by F. Roemer from the Harz, and an *Aspidichthys* has been cited by Von Koenen. A *Ctenacanthus*, seemingly undistinguishable from the *C. bohemicus* of Barrande's Étage G, has also been obtained from the Lower Devonian "Nereitenschichten" of Thuringia. A new heterostracan form (*Drepanaspis*) has lately been described by Dr. Traquair from the German Lower Devonian rocks.[1] An example of the Dipnoi (*Palædaphus devoniensis*) and an ichthyodorulite (*Byssacanthus Gosseleti*) have been obtained from the Belgian and north of France area. The Psammites de Condroz, an important member of the Upper Devonian series of Belgium, have yielded some of the actual species of fishes found in the Upper Old Red Sandstone of Scotland (*Holoptychius nobilissimus, H. giganteus, H. Flemingii*, and *Glyptopomus Kinnairdi*), besides other species of the genera *Holoptychius, Dendrodus, Lamnodus, Cricodus, Phyllolepis*, and a new genus *Pentagonolepis*.[2] It is interesting to note that these fishes are found in association with abundant traces of a land vegetation (*Archæopteris, Sphenopteris*).

The upper Fammenian psammites of Modave, in the Condroz district of Belgium, besides likewise furnishing fishes (*Holoptychius, Pterichthys, Glyptopomus, Dipterus*, &c.), have been found to contain the remains of an amphibian.[3] The late Professor Marsh recorded what he believed to be amphibian footprints from near the top of the Chemung formation of Warren County, Pennsylvania. The best preserved are nearly 4 inches long and $2\frac{1}{4}$ wide. He named the animal *Thinopus antiquus*. The same strata in which the prints lie show also ripple-marks, sun-cracks, and rain-prints, together with marine mollusks (*Nuculana*).[4] There have likewise been detected traces of insect life, but as these are chiefly met with in the Old Red Sandstone they will be referred to on p. 1003.

In the Devonian formations of North America the fish-fauna has been well preserved, the Corniferous Limestone being especially remarkable for its bone-beds, made up of the remains of vast numbers of placoderms. That limestone, a thoroughly marine deposit consisting largely of corals, must have been accumulated in comparatively deep and still waters. Many of the teeth of *Onychodus* contained in it have been

[1] *Geol. Mag.* 1900, p. 153.
[2] Lohest, *Ann. Soc. Géol. Belg.* xv. Mémoires (1888).
[3] Lohest, *op. cit.* xv. Bulletin (1888).
[4] *Amer. Journ. Sci.* ii. (1896), p. 374.

found to be broken and worn, probably indicating that these fishes were preyed on by more powerful contemporaries, whose violence or digestive energy triturated the harder parts which they swallowed. Among the fishes of this limestone are ostracoderms of the genera *Acantholepis* and *Acanthaspis*, also Arthrodira belonging to the genera *Dinichthys* and *Coccosteus*, elasmobranchs of the genus *Machæracanthus*, a ganoid of the genus *Onychodus*, together with *Macropetalichthys* and *Asterosteus*, and some forms allied to the chimæroids (*Rhynchodus*). From the Hamilton group there have also been obtained *Heteracanthus*, *Ctenacanthus*, *Callognathus*, and *Aspidichthys*.[1] In the very highest part of the Devonian series of Ohio (Black Cleveland Shale) a remarkably abundant assemblage of new and strange types of fossil fishes has been met with, including the huge Arthrodira *Dinichthys*, *Titanichthys*, and *Gorgonichthys*, together with the European genus *Coccosteus*. This fauna is especially distinguished by a number of sharks (*Cladoselache*, at least ten species).[2]

§ 2. Local Development.

Britain.[3]—The name "Devonian" was first applied by Sedgwick and Murchison to the rocks of North and South Devon and Cornwall, whence a suite of fossils was obtained which Lonsdale pronounced to be intermediate in character between Silurian and Carboniferous. The downward passage of these strata into Silurian rocks has not been satisfactorily traced by clear fossil evidence, though Lower Silurian organisms have been detected in some parts of the region. On the other hand, the Devonian rocks clearly graduate upward into Lower Carboniferous strata. Considerable difference exists between their development in the north and south of Devonshire. In the former area they consist of sandy and muddy materials in the form of sandstones, grits, and slates. In South Devonshire, on the other hand, they include thick masses of limestone and abundant volcanic intercalations in the form of tuffs (schalstein) and lavas (diabase, &c.). With these lithological contrasts there is a corresponding difference in the abundance and variety of organic remains, the calcareous rocks of Plymouth and Torquay being the chief repositories of fossils. Yet even at the best the Devonian rocks of this classical

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1 Newberry, *Monograph, U.S. G. S.* No. xvi. 1889: 'Palæontology of Ohio,' vol. ii.

2 E. W. Claypole, *Geol. Mag.* 1893, p. 443.

3 Sedgwick and Murchison, *Trans. Geol. Soc.* 2nd ser. v. p. 633. Sedgwick, *Q. J. G. S.* viii. p. 1. Lonsdale, *Proc. Geol. Soc.* iii. p. 281. R. A. Godwin-Austen, *Trans. Geol. Soc.* (2) vi. p. 433. J. W. Salter, *Q. J. G. S.* xix. p. 474. T. M. Hall, *op. cit.* xxiii. p. 371. Etheridge, *op. cit.* xxiii. (1867), p. 568, where a copious bibliography up to that date will be found; also *op. cit.* xxxvii. Address, p. 178. A. Champernowne, and W. A. E. Ussher, *op. cit.* 1879, p. 532. A. Champernowne, *op. cit.* 1889, p. 369. W. A. E. Ussher, *Geol. Mag.* 1881, p. 441; *Q. J. G. S.* 1890, p. 487; *Trans. Roy. Cornwall Geol. Soc.* xii. 1891; *Proc. Somerset. Arch. Nat. Hist. Soc.* xlvi. (1900). E. Kayser, *Neues. Jahrb.* 1889, i. p. 189. H. Hicks on the Morte Slates, *Q. J. G. S.* lii. (1896), p. 254; liii. (1897), p. 438; J. W. Gregory, *Geol. Mag.* 1897, p. 59. *Annual Reports of Geological Survey* for 1892 and subsequent years. The Devonian rocks of Cornwall and Devon have undergone much crumpling and dislocation, and have suffered considerable metamorphism. Their fossils are often singularly distorted, and mica has been almost everywhere abundantly developed in their argillaceous and calcareous portions. Much of the so-called "slate" or "killas" of these districts is a lustrous phyllite. On distortion of the fossils, see D. Sharpe, *Q. J. Geol. Soc.* iii. The remarkable cataclastic and other superinduced structures have been well described by J. B. Hill, *Trans. Roy. Cornwall Geol. Soc.* xii. 1901.

region, though they served as the type formations of the same geological age elsewhere, are much less clearly and fully developed than those of the Rhine country and other parts of the continent. It is rather from the sections and fossil collections of Central Europe than from those of England that the stratigraphy and palæontology of the Devonian system are to be determined.

This system has long been grouped into three divisions, each more or less distinctly marked off by its palæontological characters. In Devonshire and West Somerset these divisions are arranged as follows:—

	Northern Type.	Southern Type.
UPPER.	Pilton group. Slates and grits with calcareous seams (*Spirifer Verneuili*, *Athyris concentrica*, *Productus prælongus*, &c. Baggy group. Sandstones with *Cucullæa*, slates with *Lingula*, *Discina*. Pickwell-Down group. Red, green, grey, and purple slates and grits, generally unfossiliferous. Morte slates, unfossiliferous, passing down into the slates below.[1]	Slates near Ashburton with *Spirifer Verneuili*, &c. Slates of Livaton with *Clymenia*. Red and green slates with *Posidonomya venusta* and abundant *Entomis serratostriata* (= Cypridinen-schiefer). Red and grey slates with volcanic tuffs. Chudleigh limestone with *Goniatites* (*Gephyroceras*) *intumescens*, *G. acutus*, *G. simplex*, *Cardiola retrostriata*, *Rhynchonella* (*Wilsonia*) *cuboides*, *R.* (*Hypothyris*) *acuminata*, *Atrypa reticularis*, *Spirifer bifidus*, *Productus subaculeatus*, &c.
MIDDLE.	Ilfracombe slates; grey silvery slates with lenticular impure fossiliferous limestone, resting on grits and slates of Combe Martin (*Cyathophyllum cæspitosum*, &c.).	Torquay and Plymouth limestones passing laterally into slates and volcanic rocks (*Stringocephalus Burtini*, *Uncites gryphus*, *Favosites polymorpha*, &c.). Slates and limestones of Hope's Nose (*Atrypa reticularis*, *Kayseria lens*, *Spirifer speciosus*, *S. curvatus*, *Rhynchonella* (*Wilsonia*) *cuboides*, &c. = Calceola beds).
LOWER.	Hangman grits and slates (*Natica*, *Myalina*). Lynton group, grits and calcareous slates (*Spirifer hystericus*, *Chonetes sarcinulatus*, &c.) Foreland grits and slates.	Slates and greywackes (Cockington, Warberry, Meadfoot) with *Pleurodictyum problematicum*, *Homalonotus*, *Spirifer cultrijugatus*, *S. hystericus*, *Pterinea costata*, &c.

Lower.—The clay-slate of Looe, Cornwall, has yielded a species of *Pteraspis*, also *Pleurodictyum problematicum*. The lower gritty slates and limestone bands of North Devon contain, among other fossils, *Favosites* (*Pachypora*) *cervicornis*, *Cyathophyllum helianthoides*, *Petraia celtica*, *Pleurodictyum problematicum*, *Cyathocrinus* (two species), *Homalonotus* (two species), *Phacops laciniatus*, *Fenestella antiqua*, *Atrypa reticularis*, *Orthis arcuata*, *Spirifer canaliferus*, *S. lævicostus*, *Pterinea spinosa*, &c. The researches of Mr. Ussher and Professor Kayser have brought the Lower Devonian rocks of South Devon into closer palæontological relations with their equivalents on the continent. Among the species noted by these observers are—*Pleurodictyum problematicum*, *Spirifer hystericus*, *S. paradoxus* (*macropterus*), *S. cultrijugatus*, *Leptæna* (*Strophomena*) *rhomboidalis*, *Rhynchonella daleidensis*, *Chonetes sarcinulata*, *C. semiradiata*, *Pterinea costata*, *Homalonotus gigas*,—an assemblage which resembles that in the Coblenzian stage of Rhineland.

[1] Dr. Hicks claimed these slates as Silurian on the strength of some rather doubtful fossils, the more probably Devonian age of which was sustained at the time by Professor Gregory. It is possible, however, that the Morte Slates do not belong to the part of the system to which they have generally been assigned, and that the apparent order of succession in regard to them is deceptive. See the papers cited in the footnote on the previous page.

Middle.—It is in this division that limestones are best developed and fossils are most abundant. Some of the limestones of South Devon are made up of corals, and from their lenticular or sporadic occurrence suggest that they were accumulated as reefs. Large masses of limestone rapidly die out laterally and are replaced by slates. In the Ashprington district a thick group of volcanic rocks consisting of breccias and tuffs (schalstein) and diabasic lavas appears entirely to take the place of the limestones. These volcanic ejections are traceable for many miles, sometimes dwindling down and giving place to limestones or slates, and again swelling out into considerable masses.[1] They appear to have been discharged from numerous small vents across the area of south Devonshire, but no trace of any similar material has yet been detected in the northern part of the county.

The palæontological evidence makes it abundantly clear that the limestones of Torquay and Plymouth represent the great Middle Devonian limestones of France, Belgium, and Germany—the Calcaire de Givet, and the Stringocephalen-Kalk and Calceola-Kalk of the Eifel. Near Torquay shaly limestones occur containing fossils that place them on the horizon of the Eifelian group or the Calceola beds of the continent, that is, the lower division of the Middle Devonian rocks. Among these fossils are *Atrypa reticularis*, *A. aspera*, *A. desquamata*, *Kayseria lens*, *Stropheodonta* (*Leptæna*) *interstrialis*, *Pentamerus galeatus*, *Rhynchonella cuboides*, *Spirifer curvatus*, *S. speciosus*, *Orthothetes* (*Streptorhynchus*) *umbraculum*, *Productus subaculeatus*, *Phacops latifrons*, *Cyathophyllum heterophyllum*, *C. damnoniense*, *C. helianthoides*, *Cystiphyllum vesiculosum*, *Calceola sandalina*, *Favosites Goldfussi*, *Heliolites porosa*, *Stromatopora concentrica*. The massive limestones yield the characteristic fauna of the Givet or Stringocephalus limestone including the corals *Cyathophyllum helianthoides*, *C. damnoniense*, *Cystiphyllum vesiculosum*, *Alveolites*, *Favosites polymorpha*, *Striatopora denticulata*, *Amphipora ramosa*, *Heliolites porosa*, *Favosites Goldfussi*, *Stromatopora*, *Receptaculites Neptuni*, *Stringocephalus Burtini*, *Uncites gryphus*, *Magellania* (*Terebratula*) *Whidbornei*, *M. juvenis*, *Cyrtina heteroclita*, *Spirifer undiferus*, *Rhynchonella parallelopipeda*, *R.* (*Wilsonia*) *cuboides*, *R.* (*Pugnax*) *pugnus*, *Camarophoria lummatonensis*, *Pentamerus brevirostris*, *Stropheodonta interstrialis*, *Productus subaculeatus*, *Cypricardinia*, *Proëtus*, *Bronteus*, &c.[2]

Upper.—In South Devon Upper Devonian rocks are now known to be well developed and to present palæontological representatives of the several zones which have been established in this division on the continent. Three such zones have been recognised. 1st. Massive limestones which pass down continuously into those of Middle Devonian age. They contain *Rhynchonella* (*Wilsonia*) *cuboides*, *R.* (*Hypothyris*) *acuminata*, *Atrypa reticularis*, *Athyris concentrica*, *Spirifer bifidus*, *S. lineatus*, *Productus subaculeatus*, *Magellania* (*Waldheimia*) *Whidbornei*, *Merista plebeia*, *Conocardium*, *Harpes*, *Stromatopora Hüpschii*, *Actinostroma clathratum* (?) &c. 2nd, Goniatite beds which, overlying and passing down into the limestones, are marked by the presence of numerous goniatites (*Gephyroceras intumescens*, *G. complanatum*, *Beloceras sagittarium*, *Tornoceras acutum*, *T. simplex*), with *Cardiola retrostriata*, *Myalina* sp., *Sanguinolaria*, *Bactrites*, *Aveolites*. 3rd. Cypridina slates, containing ostracods (*Entomis serratostriata*) and Clymenias (*C. lævigata* and other species). These three zones may be paralleled respectively with the Frasnien and Fammenien group of the Franco-Belgian area and with the Goniatite (Adorf, Iberg) limestone, Cypridina slates and Clymenia limestone of the Eifel and Rhine.

In North Devon this palæontological grouping has not been so satisfactorily made out; but in that region there is an insensible gradation upwards through various sandy and

[1] Champernowne on the Ashprington Volcanic Series, *Q. J. G. S.* 1889, p. 369.

[2] Ussher, *Q. J. G. S.* 1890, p. 561. E. Kayser, *Neues Jahrb.* i. (1889), p. 185. Rev. G. F. Whidborne, 'A Monograph of the Devonian Fauna of the South of England,' *Monog. Palæont. Soc.*

muddy sediments into the Culm or Carboniferous system. The micaceous flaggy sandstones of Baggy Point contain *Cucullæa unilateralis* (*trapezium*, *Hardingii*), *Ptychopteria damnoniensis*, *Lingula squamiformis*, *Discina*, *Rhynchonella laticosta*, *Strophalosia productoides*, *Spirifer disjunctus*, &c. The greenish slates and calcareous bands of Pilton near Barnstaple have yielded some characteristic fossils of the uppermost part of the Devonian system, such as *Petraia celtica*, *Cyathocrinus pinnatus*, *Spirifer Verneuili*, *Athyris concentrica*, *Orthothetes* (*Streptorhynchus*) *crenistria*, *Productus prælongus*, *Strophalosia productoides*, *Rhynchonella* (*Camarotœchia*) *Partridgiæ*, and *Chonetes hardrensis*. Remains of land-plants are found in the Upper Devonian rocks of North Devon (*Bothrodendron* (*Cyclostigma*) *kiltorkense*, *Archæopteris* (*Palæopteris*) *hibernica*). The higher red and yellow sandy portions of these rocks shade up insensibly at Barnstaple in North Devon into strata which by their fossils are placed at the base of the Carboniferous Limestone series. But in no other British locality save in Devonshire can such a passage be observed. In all other places, the Carboniferous system, where its true base can be seen, passes down into the red sandy and marly strata of the Upper Old Red Sandstone.

The Devonian sedimentary rocks of Devon and Cornwall have been invaded by large bodies of granite and smaller masses of various "greenstones" (amphibolites, epidiorites, &c.), which have induced a good deal of contact-metamorphism. The intrusion of the granites took place after Lower Carboniferous time, since the Culm-measures are altered by them (pp. 728, 778). Mr. Hill has also shown that these eruptive masses are traversed by a system of joint-planes, and even a rude foliation, indicating that the powerful terrestrial movements that had so greatly crushed and disrupted the sedimentary formations had not wholly ceased when the granite appeared. The basic eruptive masses, on the other hand, appear to have been intruded after these movements had come to an end.[1]

Central Europe.—A large tract of Devonian rocks extends across the heart of Europe from the north of France through the Ardennes, the south of Belgium, Rhenish Prussia, Westphalia, and Nassau. But that the same rocks have a much wider spread under younger formations which cover them is shown by their reappearance far to the west in Brittany,[2] and to the east in the Harz and the Thuringer Wald. They present a much clearer sequence of strata than their British equivalents, for they can be seen in many places to pass down into Silurian strata as well as to graduate upward into the Carboniferous system. In the Belgian and Eifelian tracts they have been subdivided as under:—

Belgium and the North of France.[3]	Rhineland.[4]
Famennien, consisting of two facies, one sandy, the other shaly. (*b*) Psammites du Condroz (Condrusien), in which six zones are distinguished (*Cucullæa Hardingii*, *Spirifer Verneuili*, *Rhynchonella Dumonti*, *Orthis crenistria*, *Tornoceras simplex*, *Phacops latifrons*, *Dipterus*, *Asterolepis*, *Holoptychius nobilissimus*, *H.*	Younger group of Cypridina shales, with *Entomis* (*Cypridina*) *serratostriata*, *Posidonia venusta*, *Phacops cryptophthalmus*, and limestones (Kramenzelkalk) with numerous Clymenias (*C. lævigata*, *C. undulata*, *C. striata*, &c.), and Goniatites. Zone of *Paradoceras Verneuili*.

[1] *Trans. Roy. Geol. Soc. Cornwall*, xii. Part vii. 1901.

[2] A ridge of Devonian rocks stretches eastward under the Secondary formations of the south of England (where its existence has been proved by well-borings at London), and no doubt joins the Devonian area of the Boulonnais.

[3] See especially Gosselet's 'Esquisse Géologique,' and his great memoir on the Ardennes already cited; also C. Barrois, *Ann. Soc. Geol. Nord.* xxvii. (1898), p. 231.

[4] See H. von Dechen, 'Geol. Palæont. Übersicht d. Rheinprovinz,' 1884. F. Römer, 'Das Rheinische Schiefergebirge,' 1844. E. Kayser, *Z. D. G. G.* vols. xxii. (1870) to xli. (1889); *Abhand. Geol. Specialkarte Preussen*, Band II. Heft 4, 1878; *op. cit.* Neue Folg. No. 1, *Jahrb. Preuss. Geol. Landesanst.* 1881, and subsequent volumes. F. von Sandberger, 'Ueber die Entwickelung der unteren Abtheilung des Devonischen Systems in Nassau,' Wiesbaden, 1889; and papers by Koch, Frech, Holzapfel, and others.

	Belgium and the North of France.	Rhineland.
Upper.	*giganteus, Archæopteris hibernica, Sphenopteris flaccida*, &c.). (*a*) Schistes de Famenne, divisible into four zones (1) that of *Spirifer distans*, (2) of *Rhynchonella letiensis*, (3) of *Rhynchonella Dumonti*, (4) of *Rhynchonella Omaliusi*. Frasnien, varying in composition and organic contents in different parts of the Devonian basins. In the Dinant basin it consists of (*b*) Schistes de Matagne (*Atrypa reticularis, Spirifer Verneuili, Rhynchonella cuboides, Cardium palmatum, Camarophoria tumida, Entomis* [*Cypridina*] *serrato-striata, Bactrites subconicus, Tornoceras simplex, T. undulatum, Gephyroceras* [*Goniatites*] *intumescens*). (*a*) Calcaires et schistes de Frasne, shales and lenticular limestones, sometimes of great thickness, with abundant fossils (*Bronteus flabellifer, Gephyroceras* [*Goniatites*] *intumescens, Spirifer Verneuili, Sp. pachyrhynchus, Sp. orbelianus, Athyris concentrica, Atrypa reticularis, Rhynchonella cuboides, Pentamerus brevirostris, Camarophoria formosa, Receptaculites Neptuni*).	Brachiopod limestone directly overlying the Middle Devonian limestone, and containing *Rhynchonella cuboides, R. pugnus, R. acuminata, Spirifer Verneuili, Camarophoria formosa, Productus subaculeatus, Gephyroceras* (*Goniatites*) *intumescens*. Iberg limestone of Harz, Adorf limestone of Waldeck, shales of Büdesheim in the Eifel, with *Gephyroceras* (*Goniatites*) *intumescens, Rhynchonella cuboides*, and *Cardiola retrostriata*. The prevalence of this Rhynchonella has led to the group being called the "Cuboides beds," and the Goniatite has given the name of "Intumescens beds" or "Gephyroceras zone."
Middle.	Givetien.—The great limestone of the middle Devonian series, well seen at Givet, above Dinant on the Meuse, 400 metres thick. Among the abundant characteristic fossils are *Spirifer mediotextus, Sp. undiferus, Stringocephalus Burtini, Uncites gryphus, Megalodon cucullatus, Murchisonia coronata, M. bilineata, Cyathophyllum quadrigeminum, Heliolites porosa, Agoniatites, Anarcestes*. In the basin of Namur the conglomerate of Pairy-Bony lies below the limestone, and contains a band of sandstone with plants (*Lepidodendron gaspianum*). Eifélien.—Shales (Schistes de Couvin), with *Calceola sandalina, Phacops latifrons, Bronteus flabellifer, Spirifer curvatus, Sp. subcuspidatus, Sp. elegans, Athyris concentrica, Pentamerus galeatus, Strophalosia productoides*, &c.	(*b*) Stringocephalus group, consisting of the great Eifel limestone with underlying crinoidal beds (*Stringocephalus Burtini, Uncites gryphus, Spirifer undatus, Productus subaculeatus, Pentamerus galeatus, Atrypa reticularis, Macrocheilus arculatus, Pleurotomaria delphinuloides, Murchisonia bilineata, Megalodon cucullatum*, and many corals and crinoids). Zones of *Maeneceras Decheni* and *Anarcestes Denkmanni*. (*a*) Calceola group.—Marly limestones with *Athyris concentrica, Camarophoria microrhyncha, Atrypa reticularis, Merista plebeia, Spirifer speciosus, S. curvatus, Pentamerus galeatus, Rhynchonella parallelopipeda, Orthis striatula, Calceola sandalina, Cyathophyllum heliantoides, Cystiphyllum vesiculosum, Heliolites porosa, Alveolites, Favosites, Stromatopora, Phacops Schlotheimi*, &c., resting upon impure shaly ferruginous limestone and greywacke, marked by an abundance of *Spirifer cultrijugatus, Rhynchonella orbignyana, Atrypa reticularis, Phacops latifrons*, &c. Zones of *Agoniatites occultus* and *Anarcestes subnautilinus*.
Lower.	Coblenzien, composed of greywacke, sandstones, shales, and conglomerate, having a united thickness of sometimes 7000 or 8000 feet, and divisible into five sub-groups as under:— 5. Greywacke of Hierges with (*b*) Zone of *Spirifer cultrijugatus, Calceola sandalina*. (*a*) Zone of *Spirifer arduennensis, Pterinea lineata*. 4. Red slates of Vireux and conglomerate of Burnot. 3. Black sandstone of Vireux (Ahrien). 3. Greywacke of Montigny with *Spirifer paradoxus, Athyris undata, Leptæna rhomboidalis* (*Strophomena depressa*) (Hundsrückien). 1. Sandstone of Anor (Taunusien). Gedinnien, comprising an upper group of shales and sandstones and a lower group of fossiliferous shales, quartzo-phyllades, quartzites, and conglomerates. The fossils in the lower group comprise *Dalmanites, Homalonotus Roemeri, Primitia Jonesii, Tentaculites grandis, T. irregularis, Spirifer Mercuri, Orthis Verneuili, Pterinea ovalis*, &c. The base of the Devonian system lies unconformably on Cambrian rocks.[1]	Coblenz group (Spirifer sandstone) divisible into the three following sub-groups:— (*c*) Upper greywacke and slate (Coblenz, Ems, Daleiden) with *Ctenocrinus decadactylus, Spirifer auriculatus, S. curvatus, S. paradoxus, Atrypa reticularis, Chonetes dilatata, Homalonotus lævicauda, Cryphæus laciniatus*. (*b*) Coblenz quartzite probably on the horizon of the Burnot conglomerate in the Eifel. (*a*) Greywacke with *Strophomena laticosta, Orthis circularis, Spirifer dunensis, Homalonotus ornatus, H. crassicauda, Phacops latifrons*. Slates (Hundsrück, Taunus) with numerous trilobites (*Homalonotus planus, Dalmanites rhenanus, Phacops Ferdinandi, Cryphæus, Orthoceras, Goniatites*, &c.). Taunus quartzite, Siegen grauwacke (*Spirifer primævus, S. hystericus, Rensselæria, Tentaculites grandis, Homalonotus Roemeri*, &c.). Sandstones, slates, phyllites, arkoses, ending downwards in conglomerates. The Lower Devonian series contains the zone of *Agoniatites fidelis* and *Anarcestes precursor*, and that of *Tornoceras inexpectatum*.

[1] For an account of the Lower Devonian fauna of this region see Gosselet, *Ann. Soc. Géol.*

In the Harz, according to the researches of Römer,[1] Lossen,[2] Kayser, Koch, and others,[3] the Devonian system, largely developed, consists of (1) a lower group of quartzites, greywackes, flinty slates, clay slates, and associated bands of diabase (classed as "Hercynian"), lying above the graptolitic Wieda shales and Tanne greywacke (p. 976); (2) a middle group composed of (*a*) Calceola-beds (*Spirifer cultrijugatus*, *Calceola sandalina*) and (*b*) Stringocephalus limestone, consisting of a lower crinoidal band and a massive limestone; and (3) an upper group consisting of (*a*) Cuboides-beds, limestones and marls, (*b*) Goniatite shales, (*c*) Cypridina shales. The eastern part of the region consists mainly of greywackes and slates which, with their associated igneous rocks, attain a great thickness in the Wieda slates. These slates are partly Upper Silurian, since they contain a number of simple graptolites, while the limestones underneath yield abundant trilobites (*Dalmanites*, *Cryphæus*, *Phacops*, *Bronteus*, *Acidaspis*).

Representatives of the Devonian system reappear with local petrographical modifications, but with a remarkable persistence of general palæontological characters, in Eastern Thuringia, Franconia, Saxony, Silesia, the north of Moravia, and East Gallicia. In Thuringia, where the stratigraphical succession can be traced from Cambrian rocks through Lower and Upper Silurian, the Devonian system lies unconformably on these older formations, and is represented by (1) a Lower series of calcareous shales with *Tentaculites*, interstratified with bands of quartzite (*Nereites*) at the top, and lenticular limestones with *Ctenacanthus* at the bottom, and including interstratified diabase lavas towards the east; (2) a Middle series of dark shales, greywackes, and rare limestones, but with diabase tuffs and lavas towards the east (*Atrypa reticularis*, corals); (3) an Upper series of nodular limestones with Goniatites (*Gephyroceras intumescens*, *G. retrorsum*, *Beloceras sagittarium*), various Clymenias; green and red shales with *Posidonomya venusta* and *Entomis serrato-striata*. In the eastern part of the country this upper subdivision likewise includes numerous interstratified diabase-lavas with tuffs and volcanic breccias.[4]

In Bohemia, as already stated, the greater part of Barrande's Stage F and the whole of G and H, which he classed in his third fauna or as Upper Silurian, are now placed in the Devonian system.[5] The following table gives the German equivalents of his subdivisions:—

Stage H_2	Givetian	Upper Stringocephalus beds of the Eifel. Massen-Kalk of Hesse Nassau.
Stage H_1		Lower Stringocephalus beds of the Eifel. Odershaüser-Limestone of Hesse Nassau.
G_3, G_2		Eifelian, Calceola group of the Eifel. Günteroder-Limestone of Hesse Nassau.
G_1		Coblenzian, *Spirifer cultrijugatus* beds of the Eifel. Ballersbach Limestone of Hesse Nassau. Greifenstein Limestone.
F (part)		Lower Devonian.

Farther east, in the district of Russian Poland, which lies between Sandomir and Kielce to the west of the Vistula, a large development of Devonian rocks is to be seen, including representatives of all the three divisions. The equivalents of the Ludlow rocks already noticed (p. 976) are followed by hard quartzose sandstones with numerous fossils (*Spirifer auriculatus*, *S. macropterus*, *S. carinatus*, *S. subcuspidatus*, *S. lævicosta*, *Chonetes sarcinulata*, *Orthis orbicularis*, *Tentaculites*, *Cryphæus*, &c.), and by a sandstone which contains fragmentary fish remains (*Psammosteus*, *Coccosteus*, &c.). The Middle division is more fully represented and has yielded a large assemblage of organic remains. In its lower half, consisting of sandstones, shales, marls, limestones, and dolomites, there

Nord. xiii. (1886), p. 292. The spirifers of the Belgian Coblenzian rocks have been described by F. Béclard, *Bull. Soc. Belg. Géol.* ix. (1895), p. 129.

[1] 'Versteinerungen des Harzgebirges,' 1843; 'Rheinisch. Uebergangsgebirge,' 1844.

[2] Geologisch. Uebersichtskarte Harz,' 1881.

[3] See *Abhand. Preuss. Geol. Landesanst.* ii. 4; iv. 2; viii. 4; ix. 2; Neue Folge, Nos. 1, 16, 17.

[4] Barrois, *Ann. Soc. Géol. Nord.* xx. (1892), p. 67.

[5] See Professor Kayser's papers on this subject cited *ante*, p. 974.

occur *Calceola sandalina*, *Atrypa reticularis*, *Chonetes sarcinulata*, *Stringocephalus Burtini*, *Pentamerus galeatus*, *Bronteus*, *Phacops latifrons*, *Proëtus*, &c., while in its upper half, which includes fetid and other limestones and shales, there are found numerous corals and other fossils (*Stromatopora*, *Amphipora ramosa*, *Heliolites porosa*, *Atrypa reticularis*, *A. aspera*, *Stringocephalus Burtini*, *Acidaspis*, &c.). These strata graduate upward into the Upper division, which consists largely of sheets of limestone, and shales or marl. The lowest limestone has yielded upwards of 60 species, among which are *Orthis striatula*, *Martinia inflata* and *Rhynchonella cuboides*, with species of *Bronteus*, *Acidaspis* and *Cyphaspis*. A higher limestone contains a number of cephalopods, *Orthoceras*, *Manticoceras*, *Gephyroceras calculiforme*, *Tornoceras* (three species) with *Tentaculites tenuicinctus*, *Cardiola retrostriata*. Still higher up are found *Entomis*, three species, *Phacops*, *Trimerocephalus typhlops* (*Phacops cryptophthalmus*), *Cyrtoclymenia*, *Goniatites*. The uppermost strata are specially characterised by their Clymenias (*Cyrtoclymenia*, *Platyclymenia*) and species of *Entomis*, and are no doubt the equivalent of the *Cypridina*-shales and *Clymenia*-limestones of Germany.[1]

Among the crumpled formations of the Styrian Alps, the evidence of organic remains has revealed the presence of Upper Devonian rocks with abundant Clymenias, Middle Devonian limestones with the characteristic *Stringocephalus* and numerous corals, and Lower limestones and slates with cephalopods and brachiopods.[2] Perhaps in other tracts of the Alps, as well as in the Carpathian range, similar shales, limestones, and dolomites, though as yet unfossiliferous, but containing ores of silver, lead, mercury, zinc, cobalt, and other metals, may be referable to the Devonian system.

In France and Belgium the Devonian system has long been recognised (table, p. 991). Its middle and upper members (Givetian, Frasnian, Famennian) are well exposed in the Boulonnais. In Normandy and Maine, sandstones (with *Orthis Monnieri*), are followed by limestones (with *Homalonotus*, *Cryphæus*, *Phacops*, &c.), and by upper greywackes and shales (with *Pleurodictyum problematicum*).[3] In Brittany also, Devonian strata are found, including representatives of the Famennian groups with Cypridinas and Goniatites, shales and limestones with Eifelian cephalopods, *Pleurodictyum problematicum* and *Spirifer cultrijugatus*, and a series of greywackes, sandstones, and shales with *Chonetes sarcinulata*, *Phacops latifrons*, &c.[4] In this region lies the limestone of Erbray (Loire Inférieure), so fully described by Barrois, who, from its abundant corals, numerous brachiopods and gasteropods, and its trilobites of the genera *Calymene*, *Phacops*, *Dalmanites*, *Proëtus*, *Harpes*, *Bronteus*, and *Cheirurus*, places it in the Gedinnian group at the base of the Lower Devonian series, and compares it with the Hercynian limestones of the Harz.[5] In the remarkable oasis of ancient rocks which has been already referred to as forming a conspicuous feature among the younger formations of Languedoc, representatives of the three great divisions of the Devonian system have been worked out by F. Frech.[6] Again, the central Silurian zone of the Pyrenees is flanked on the north and south by bands of Devonian rocks (with broad-winged spirifers and other characteristic fossils), which have been greatly disturbed

[1] G. Gürich, 'Das Palæozoicum des Polnischen Mittelgebirges,' *Verh. Russ. Min. Ges.* 2nd ser. xxxii. (1896), pp. 1-539, with map and plates of fossils. This paper is a detailed monograph of the older Palæozoic rocks of Poland, more especially of the Devonian formations, with palæontological descriptions of the fossils.

[2] G. Stache, *Z. D. G. G.* 1884, p. 358. Frech, *op. cit.* 1887, p. 660 (and authors there cited); 1891, p. 672; 1894, p. 446; 1896, p. 199, and his 'Die Karnischen Alpen,' 1894.

[3] Oehlert, *B. S. G. F.* xiii. (1884), p. 6; xvii. (1889), p. 742. Barrois, *op. cit.* xiii. p. 7; *Ann. Soc. Géol. Nord*, xiii. (1886), p. 170.

[4] Barrois, *Ann. Soc. Géol. Nord*, iv. xvi. xxvii.

[5] 'Faune du Calcaire d'Erbray,' *Mém. Soc. Géol. Nord*, iii. (1889); *Ann. Soc. Géol. Nord*, xiii. (1886), p. 74.

[6] *Z. D. G. G.* xxxix. (1887), p. 402.

and altered. In the Asturias, according to Barrois, a mass of strata about 3280 feet thick contains representatives of the three divisions of the Devonian series, and has yielded an abundant fauna, numbering upwards of 180 species, among which the corals and brachiopods are specially abundant.[1] In the Spanish peninsula numerous outcrops of Devonian rocks have been noticed.

Throughout Central Europe there occurs, in many parts of the Devonian areas, evidence of contemporaneous volcanic action in the form of intercalated beds of diabase, diabase-tuff, schalstein, &c. These rocks are conspicuous in the "greenstone" tract of the Harz, in Nassau, Saxony, Westphalia, the Fichtelgebirge, and, as above stated, in Thuringia. Here and there the tuff-bands are crowded with organic remains. It is also deserving of remark that over considerable areas (Ardennes, Harz, Sudeten-Gebirge, &c.) the Devonian sedimentary formations have assumed a more or less schistose character, and appear as quartzo-phyllades, quartzites, and other more or less crystalline rocks which were at one time supposed to belong to the "Archæan" series, but in which recognisable Devonian fossils have been found (pp. 709, 800). At numerous places, also, they have been invaded by masses of granite, quartz-porphyry, or other eruptive rocks, round which they present the characteristic phenomena of contact-metamorphism (pp. 778, 783). These changes may have led to the subsequent development of the abundant mineral veins (Devon, Cornwall, Westphalia, Harz, &c.), whence large quantities of iron, tin, copper, and other metals have been obtained.

Russia.—In the north-east of Europe the Devonian and Old Red Sandstone types appear to be united, the limestones and marine organisms of the one being interstratified with the fish-bearing sandstones and shales of the other. In Russia, as was shown in the great work 'Russia and the Ural Mountains,' by Murchison, De Verneuil, and Keyserling, rocks intermediate between the Upper Silurian and Carboniferous Limestone formations cover an extent of surface larger than the British Islands.[2] This wide development arises, not from the thickness, but from the undisturbed horizontal character of the strata. Like the Russian Silurian deposits, they remain to this day nearly as flat and unaltered as they were originally laid down. Judged by mere vertical depth, they present but a meagre representation of the massive Devonian greywacke and limestone of Germany, or of the Old Red Sandstone of Britain. Yet, vast as is the area over which they constitute the surface-rock, it probably forms only a small portion of their total extent; for they rise up from under the newer formations along the flank of the Ural chain. It would thus seem that they spread continuously across the whole breadth of Russia in Europe. Though almost everywhere undisturbed, they afford evidence of terrestrial movement immediately previous to their deposition, for they gradually overlap Upper and Lower Silurian rocks.

In the north-western parts of the Empire three lithological groups are the prominent constituents of the Devonian series, the lower consisting chiefly of sandstones with subordinate marls and clays; the middle, of limestones and dolomites, and the upper almost wholly of sandstones. As these subdivisions are traced into the centre of the country, this threefold arrangement ceases to be traceable, the strata being there almost wholly limestones and dolomites. The sandstones are distinguished by the numbers of fossil fishes which they contain, but are poor in shells, only yielding small examples of *Lingula*. The limestones, on the other hand, are crowded with an abundant and varied fauna. Those of the middle subdivision in the north-western region have been ranged in four

[1] "Recherches sur les Terrains anciens des Asturies," &c., *Mém. Soc. Géol. Nord*, ii.; *Ann. Soc. Géol. Nord*, vi. (1879), p. 270; xii. (1886), p. 124; xx. (1892), p. 61. J. Roussel, *Bull. Carte, Géol. France*, No. 35 (1893).

[2] Besides the great work of these three pioneers, the student will find much recent information regarding Russian geology in the *Mémoires du Comité Géologique* of Russia. See for Devonian data T. Tschernychew, vols. i. iii. (a detailed memoir on the lower, middle, and upper divisions of the system in the Ural region).

horizons. Of these the lowest, which reposes immediately on the sandstones, is marked by the occurrence of *Rhynchonella Meyendorfii*, *R. livonica*, *Spirifer muralis*, *Strophomena productoides*, *Atrypa reticularis*, *Orthis striatula*, *Aviculopecten Ingriæ*, *Bellerophon trilobatus*, &c. The second platform contains a somewhat different fauna, distinguished by the association of *Spirifer muralis*, *S. Archiaci*, and *S. tenticulum*. The organisms of the third horizon are more distinct and typical, some of the more important being *Spirifer Verneuili*, *Cyrtina heteroclita*, *Athyris Helmersenii*, *Favosites polymorpha*, *Cyathophyllum hexagonum*, *Orbiculoidea* (*Discina*) *nitida*, *Rhynchonella* (*Pugnax*), *pugnus*; numerous lamellibranchs, as *Avicula Buchii*, *Pterinea triangularis*, *Myalina acutirostris*, and also *Murchisonia pusilla*, *Bellerophon lineatus*, *Gomphoceras cyclops*, *Phragmoceras inversum*, &c. The fourth horizon is marked by abundance of *Spirifer Anossofi*. These four divisions are supposed to represent the *Stringocephalus*-limestone and *Calceola*-group of Central Europe.[1]

As was first signalised by Murchison and his associates, a special interest attaches to these Russian strata, inasmuch as they display the union of the elsewhere more or less distinct Devonian and Old Red Sandstone types. While the calcareous bands contain organisms of known Devonian species, the sandstones afford remains of fishes, some of which are specifically identical with those of the Old Red Sandstone of Scotland. The distribution of these two palæontological facies in Russia was traced by Murchison to the lithological characters of the rocks, and consequent original diversities of physical conditions, rather than to differences of age. Indeed, cases occur where, in the same band of rock, Devonian shells and Old Red Sandstone fishes lie commingled. In the belt of the formation which extends southwards from Archangel and the White Sea, the strata consist of sands and marls, and contain only fish remains. Traced through the Baltic provinces, they are found to pass into red and green marls, clays, thin limestones and sandstones, with beds of gypsum. The lower parts of the series contain *Osteolepis*, *Dipterus*, *Diplopterus*, and *Asterolepis* (*Homosteus*), while in the higher beds *Holoptychius*, *Bothriolepis*, and other well-known fishes of the Upper Old Red Sandstone occur. Followed still farther to the south, as far as the watershed between Orel and Woronesch, the Devonian rocks lose their red colour and sandy character, and become thin-bedded yellow limestones, and dolomites with soft green and blue marls. Traces of salt deposits are indicated by occasional saline springs. It is evident that the geographical conditions of this Russian area during the Devonian period must have resembled those of the Rhine basin and Central England during the Triassic period. There is an unquestionable passage of the uppermost Devonian rocks of Russia into the base of the Carboniferous system, but a complete break between them and the highest Silurian strata. The lowest parts of the British Old Red Sandstone, containing *Pterygotus*, *Cephalaspis*, *Pteraspis*, &c., are wanting.

Asia.—From the Ural chain eastwards, the Devonian system stretches into the heart of Asia. Devonian fossils have been recognised in the region of the Altai, where the limestone of Krjukowsk has yielded *Phacops altaicus*, *Harpes reticulatus*, *Bronteus sibiricus*, *Proëtus Oehlerti*, *Dalmanites*, *Goniatites* (*Anarcestes*) *lateseptatus*, *Orthoceras ulbense*, *Platyceras disjunctum*, *Meristella ypsolon*, *Meristina* (*Whitfieldia*) *tumida*, *Athyris undata*, *Spirifer sibiricus*, &c.—an assemblage that may represent the Coblenzian group of the typical Rhineland series.[2] Richthofen brought from south-western China a series of marine fossils which show the presence there of strata probably referable to Middle and Upper Devonian horizons. Out of 28 species named by Kayser, no fewer than 13 are cosmopolitan, including such familiar forms as *Rhynchonella cuboides*, *R. pugnus*,

[1] P. N. Wenjukoff, 'Die Fauna des Devonischen Systems im nordwestlichen und centralen Russland,' St. Petersburg, 1886. This paper deals only with the invertebrate fossils, and leaves out the distribution of the abundant ichthyolites.

[2] T. Tschernychew, 'Materialien zur Kenntniss der Devonischen Fauna des Altai's,' St. Petersburg, 1893.

Pentamerus galeatus, *Atrypa reticularis* (var. *desquamata*), *Merista plebeia*, *Spirifer Verneuili*, *Orthis striatula*, *Productus subaculeatus*, *Strophalosia productoides*, *Aulopora tubæformis*.[1]

In the Hindu Khoosh Devonian fossils have been obtained from the right bank of the Chitral river, consisting of corals and brachiopods (*Favosites*, *Cyathophyllum*, *Orthis striatula*, *Spirifer extensus*, *S. disjunctus*, *Athyris concentrica*, *Atrypa aspera*, *Rensselaria strigiceps*).[2]

North America. The Devonian system, as developed in the Northern States, and eastern Canada and Nova Scotia, presents much geological interest in the union which it contains of the same two distinct petrographical and biological types found in Europe. Traced along the Alleghany chain, through Pennsylvania, into New York, the Devonian rocks are found to contain a characteristic suite of marine organisms comparable with those of the Devonian system of Europe. But on the eastern side of the great range of Silurian hills we encounter in the north-eastern States, New Brunswick and Nova Scotia, a succession of red and yellow sandstones, limestones, and shales nearly devoid of marine organisms, yet full of land-plants, and with occasional traces of fish remains.[3]

The marine or Devonian type has been grouped in the following subdivisions by the geologists of New York:

UPPER.	Catskill Red Sandstone, with fish remains (*Holoptychius*, &c.). Chemung group (*Spirifer Verneuili*). Portage group (*Goniatites*, *Cardiola*, *Clymenia*). Genesee group (*Rhynchonella* cf. *cuboides*).
MIDDLE.	Hamilton group (*Phacops*, *Homalonotus*, *Cryphæus*). Marcellus group (*Goniatites*).
LOWER.	Corniferous limestone (*Spirifer acuminatus*, *S. gregarius*, *Dalmanites*, *Proetus*). Onondaga limestone, Schoharie grit, Cauda-galli grit, Esopus slate. (This and the Corniferous limestone are bracketed together as the Upper Helderberg group). Oriskany sandstone[4] (*Spirifer arenosus*, *Rensselaria ovoides*).

In the Lower Devonian series, traces of terrestrial plants (*Psilophyton*, *Caulopteris*, &c.) have been detected, even as far west as Ohio. Corals (cyathophylloid forms, with *Favosites*, *Syringopora*, &c.) abound, especially in the Corniferous Limestone, perhaps the most remarkable mass of coral-rock in the American Palæozoic series, from which Hall gathered a magnificent collection of specimens. Among the brachiopods are species of *Pentamerus*, *Stricklandinia*, *Rhynchonella*, and others, with the characteristic European form *Spirifer cultrijugatus*, and the world-wide *Atrypa reticularis*.

[1] Richthofen, 'China,' iv. p. 75. Abundantly fossiliferous Devonian rocks have been found in the provinces of Yunan and Kwei Chau (Douvillé, *Compt. rend.* 26th Feb. 1900), and more recently some beds of anthracite interstratified among the shales and limestones (G. H. Monod, *op. cit.* 4th Feb. 1901).

[2] General M'Mahon and Mr. Hudleston, *Geol. Mag.* 1902, pp. 3, 49.

[3] See a suggestive paper on 'Palæozoic Seas and Barriers in Eastern North America,' by E. O. Ulrich and C. Schuchert, *Bull. New York State Mus.* No. 52 (1902), p. 633.

[4] As already stated (p. 977), there is a difference of opinion among American geologists as to where the base of the system should be placed. Professor H. S. Williams thinks it comes between the Lower and Upper part of the Oriskany group (*Bull. Geol. Soc. Amer.* xi. 1900, p. 346); Mr. Prosser places the line at the base of the Cauda-galli grit (*B. U. S. G. S.* No. 120, 1894); others, like Dr. J. M. Clarke and Mr. Schuchert, would include the Lower Helderberg group as the base of the Devonian (*B. Geol. Soc. Amer.* xi. p. 241; *Mem. New York State Mus.* iii. No. 3, 1900). In this Memoir Dr. Clarke fully discusses the Oriskany fauna. Other recent papers by this able palæontologist will be found in the *Bulletin* of the same Museum, Nos. 39, 49, 52. See also his paper on the Oneonta, Ithaca, and Portage formation in *15th Ann. Rep. State Geologist, New York*, 1895.

The trilobites include the genera *Dalmanites*, *Proëtus*, and *Phacops*. Remains of fishes occur in the Corniferous group, consisting of ichthyodorulites and teeth of cestraciont and hybodont placoids, with plates, bones, and teeth of some peculiar forms (*Macropetalichthys*, *Onychodus*).

In the Marcellus shale, Hamilton beds, and Genesee shale remains of land plants occur, but much less abundantly than among the rocks of New Brunswick. Brachiopods are especially numerous among the sandy beds in the centre of the formation. They comprise, as in Europe, many broad-winged spirifers (*S. pennatus* [*mucronatus*], &c.), with species of *Productus*, *Chonetes*, *Athyris*, &c. The earliest American goniatites have been noticed in these beds.

The Portage and Chemung groups in the Eastern districts have yielded land plants and fucoids, also some crinoids, numerous broad-winged spirifers, with Avicula and a few other lamellibranchs, but in Western New York a more abundant pelagic fauna (Naples) is presented, especially rich in goniatites (*Manticoceras*, numerous species, *Gephyroceras*, *Probeloceras*, *Beloceras*, *Sandbergeroceras*, *Tornoceras*, *Bactrites*), and Clymenias (*Gyroclymenia*).[1] These strata consist of shales and laminated sandstones, which attain a maximum thickness of upwards of 2000 feet, but die out entirely towards the interior. They pass up insensibly into a mass of red sandstones and conglomerates —the Catskill group,[2] which is 2000 or 3000 feet thick in the Catskill Mountains, and thickens along the Appalachian region to 5000 or 6000 feet. These red arenaceous rocks bear a striking similarity in their lithological and biological characters to the Old Red Sandstone of Europe. As a whole they are unfossiliferous, but they have yielded some ferns like those of the Upper Old Red Sandstone of Ireland and Scotland (*Archaeopteris hibernica* and a number of American species, *Cyclopteris*, &c.) some characteristic genera of fish, *Bothriolepis*, *Holoptychius*, *Glyptopomus*, *Dipterus*, *Gyracanthus*, and a large lamellibranch closely resembling the Irish *Amnigenia* or *Anodonta*. From the Black Shale of Ohio at the top of the system and immediately below the base of the Carboniferous series, the gigantic fishes were obtained to which reference was made on p. 988.

Devonian formations not only stretch over the eastern part of the continent from Canada into northern New England and through the States of New York and Pennsylvania into West Virginia, but to the west of the Appalachian region they spread through Ohio and Michigan into Illinois, Missouri, and Iowa. They reappear in force to the west of the Rocky Mountains, being displayed in Nevada in a mass of limestone 6000 feet thick, followed by shales and quartzite, and with a remarkable similarity of fauna from bottom to top, though some Lower Devonian forms are found in the lowest 3500 feet and Upper forms in the highest parts. The system extends still farther west into California, where some of its limestones are true coral reefs, associated with slates and schists, and are believed to lie about the platform of the Corniferous group of the eastern region or the base of the Middle Devonian series. They contain species of *Favosites*, *Cyathophyllum*, *Acervularia*, *Alveolites*, *Syringopora*, *Monticulipora*, *Loxonema*, *Murchisonia*, *Bellerophon*, *Orthoceras*, &c.[3] The Devonian formations of New York and Pennsylvania cross into Canada, where they spread over a wide tract in Ontario, and have yielded an abundant series of marine fossils, the Corniferous and Hamilton groups being particularly well developed. They extend across the district of Keewatin, to the west and south-west of James Bay, then northwards through Hudson's Bay to Southampton Is-

[1] J. M. Clarke, "The Naples Fauna, with *Manticoceras intumescens*, in Western New York," 16*th Ann. Rep. State Geologist, New York*, 1898.

[2] On this group see J. J. Stevenson, *Proc. Amer. Assoc.* xl. (1891), Vice-President's Address to Geol. Section; *Amer. Journ. Sci.* xlvi. (1893), p. 330. N. H. Darton, *op. cit.* xlv. (1893), p. 203. Messrs. J. M. Clarke and Schuchert have proposed a revised classification of the whole of the older Palaeozoic formations of New York, *Science*, x. (1899), p. 874.

[3] J. S. Diller and C. Schuchert, *Amer. Journ. Sci.* xlvii. (1894), p. 416. See C. S. Prosser, *Bull. U.S. G. S.* No. 120 (1894).

land and westward into Manitoba, the Northwest Territories and the chain of the Rocky Mountains. In the Middle and Upper groups of Manitoba, which are highly fossiliferous, a number of forms occur which cannot at present be distinguished from European species (*Cladopora cervicornis, Productella productoides, Stringocephalus Burtini, Atrypa reticularis,*[1] &c.).

Australasia.—In New South Wales, the presence of Devonian rocks was determined by W. B. Clarke from the evidence of fossils. The thickness of strata (sandstones, quartzites, conglomerates, shales, and limestones) is in some places estimated at not less than 10,000 feet, passing down into Silurian and upwards into Carboniferous strata. Among the numerous fossils are many forms familiar in corresponding strata in Europe and North America, such as *Cyathophyllum damnoniense, Favosites reticulata, F. fibrosa, F. Goldfussi, Heliolites porosa, Chonetes languessiana* (*hardrensis*), *Orthis striatula, Rhynchonella pleurodon, R. pugnus, Atrypa reticularis, Spirifer Verneuili.*[2] In Victoria, certain limestones found at Bindi, on the Tambo river, and elsewhere, have yielded characteristically Middle Devonian fossils, including *Favosites Goldfussi, Spirifer lævicostatus, Chonetes australis,* and a placoderm fish. With these rocks are associated contemporaneous felsitic lavas and tuffs. Other strata are referred to the Upper Devonian series.[3]

Rocks, which may be of Devonian age, play an important part in the structure of New Zealand. They are the oldest known rocks in the North Island, and are said to reach a thickness of from 7000 to 10,000 feet in the South Island, but as they are highly folded their dimensions may not be so great. They have yielded some brachiopods (*Spirifer vespertilio*), and are said also to contain *Homalonotus expansus,* and some plant remains. They are pierced by granite, near which in some places they are traversed by gold reefs.[4]

II. OLD RED SANDSTONE TYPE.

§ 1. General Characters.

Under the name of Old Red Sandstone, is comprised a thick series of red sandstones, shales, and conglomerates, intermediate in age between the Ludlow rocks of the Upper Silurian series and the base of the Carboniferous system in Britain. These rocks were termed "Old" to distinguish them from a somewhat similar series overlying the Coal-measures, to which the name "New" Red Sandstone was applied. When the term Devonian was adopted it speedily supplanted that of Old Red Sandstone, inasmuch as it was founded on a type of marine strata of wide geographical extent, whereas the latter term described what appeared to be merely a British and local development. For the reasons already given, however, it is desirable to retain the title Old Red Sandstone as descriptive of a remarkable suite of deposits to which there is little or nothing analogous in typical Devonian rocks. The Old Red Sandstone of Europe is most characteristically developed in the British Isles. It was probably deposited in separate areas or basins, the sites of some of which can still be traced. The diversities of sediment and of organic contents of these basins point

[1] J. F. Whiteaves, Address to Sec. E. *Amer. Assoc.* 1899.

[2] See the authors cited on pp. 979, 980.

[3] R. A. F. Murray, 'Victoria: Geology and Physical Geography,' 1887.

[4] Hector, 'Handbook of New Zealand,' p. 36; F. W. Hutton, *Trans. New Zealand Inst.* (1889), p. 163.

to the absence, or at least rare occurrence, of any direct communication between them. Nevertheless the presence of some of the same species of fishes in different basins, and also in marine Devonian strata at a distance, probably indicates that from time to time organisms did pass between these more enclosed waters and the open sea. It was maintained many years ago by Fleming and still more explicitly by Godwin Austen, and was afterwards enforced by A. C. Ramsay, that these basins were lakes or inland seas. The character of the strata, the absence of unequivocally marine fossils, the presence of land-plants, myriapods, and numerous ganoid fishes, which have their modern representatives in rivers and lakes, suggest and support this opinion, which has been generally adopted by geologists.[1] The red arenaceous and marly strata which, with their fish remains and land-plants, occupy a depth of many thousand feet between the top of the Silurian and the base of the Carboniferous systems, are regarded as the deposits of a series of lakes or inland seas formed by the uprise of portions of the Silurian sea-floor, and usually cut off from the open sea, which, however, may have gained occasional access to them. The length of time during which these enclosed basins must have existed is shown, not only by the thickness of the deposits formed in them, but by the complete change which took place in the marine life between the Silurian and Carboniferous periods. The prolific fauna of the Wenlock and Ludlow rocks was driven away from western Europe by the geographical revolutions which, among other changes, produced the lake-basins of the Old Red Sandstone. When a marine population—crinoids, corals, and shells—once more overspread that area, it was a completely different one. So thorough a change must have demanded a long interval of time.

Rocks.—As shown by the name of the type, red sandstone is the predominant rock. The colour varies from a light brick red to a deep chocolate-brown, and occasionally passes into green, yellow, or mottled tints. The sandstones are for the most part granular siliceous rocks, wherein the component grains of clear quartz are coated and held together by a crust of earthy ferric oxide. In no part of the geological record is the prevalence of this red material more marked than in the Old Red Sandstone. The conditions that led to the precipitation of this oxide in such quantity are not yet well understood.[2] Scattered pebbles of quartz or of various crystalline rocks are frequently noticeable among the sandstones, and this character affords a passage into conglomerate. The latter rock forms a conspicuous feature in many Old Red Sandstone districts. It varies in thickness from a mere thin layer up to successive massive beds, having a united thickness of several thousand feet. The pebbles vary much in composition, consisting of quartz, quartzite, greywacke, granite, syenite, quartz-porphyry, gneiss, felsite, or other durable material, and their varying nature serves to distinguish some bands of conglomerate from others. They are of all sizes up to blocks

[1] For a history of opinion on this subject see A. G., *Trans. Roy. Soc. Edin.* xxviii. p. 346.

[2] See *postea*, p. 1006. Mr. I. C. Russell concludes that in the majority of cases the ferric oxide was deposited during the subaerial decay of the rocks from which the sediment was derived. *B. U. S. G. S.* No. 52 (1889).

eight feet or more in length. They are sometimes tolerably angular, particularly where the conglomerate rests upon schists or other rocks which weather into angular blocks. In the upper Old Red Sandstone, thick accumulations of subangular conglomerate or breccia recall some glacial deposits of modern times (p. 1011). The stones in the conglomerates are generally well rounded, sometimes indeed remarkably so, even when they are a foot or more in diameter. The larger blocks are usually more angular fragments that have been derived from rocks in the immediate neighbourhood. The smaller rounded stones have often come from some distance; at least it is impossible to discover any near source for them. Bands of red and green clay or marl occur, in which seams and nodules of cornstone may not infrequently be observed. Here and there, too, the sandstones assume a flaggy character, and sometimes pass into fine grey or olive-coloured shales and flagstones. Organic remains occur in some of these grey beds, but are usually absent from the red strata, though in some of the conglomerates teeth, scales, and broken bones of fishes are not uncommon. In the north of Scotland, peculiar very hard calcareous and bituminous flagstones are largely developed, and have yielded the chief part of the remarkable ichthyic fauna of the system. In Scotland, also, contemporaneously erupted andesites, diabases, agglomerates, and tuffs play an important part in the petrography of the Old Red Sandstone, seeing that they attain a thickness in some places of more than 6000 feet, and form important ranges of hills. They point to the existence of extensive volcanic eruptions from numerous vents in the inland basins in which the sediments were accumulated.

LIFE.—No greater contrast is to be found between the organic contents of any two successive groups of rock than that which is presented by a comparison of the Upper Silurian and Old Red Sandstone systems of Western Europe. The abundant marine fauna of the Ludlow period disappeared from the region. As soon as the red rocks begin, the fossils diminish in number and soon die out. But the geographical changes probably took place slowly. The peculiar conditions under which the red sediments were laid down began to show themselves while the Upper Silurian fauna still flourished in the waters, so that some of the uppermost fossiliferous Silurian strata (Downtonian and Tile-stones) are quite red.

Some traces of the aquatic plants that grew in the fresh-water lakes have been detected. An abundant fossil, originally referred to the vegetable kingdom and named *Parka* by Fleming, was afterwards considered to be more probably the egg-packets of the large crustaceans which abounded in these waters. More recently, however, this organism has been carefully studied by Sir J. W. Dawson and Professor D. P. Penhallow, who came to the conclusion that it represents what were aquatic plants with creeping stems, linear leaves, and sessile sporocarps bearing two kinds of sporangia.[1] On the land that surrounded the lakes or inland seas of the period, there grew the oldest terrestrial vegetation of which more than mere fragments are known. It has been scantily

[1] *Trans. Roy. Soc. Canada*, ix. (1891), sect. iv. pp. 3-16.

preserved in the ancient lake-bottoms in Europe; more abundantly in Gaspé and New Brunswick. The American localities yielded to the long-continued researches of Sir J. W. Dawson more than 100 species of land-plants. They are almost all vascular cryptogams, lycopods and ferns being largely predominant. Among the equisitaceæ are *Asterocalamites*, *Calamocladus*, *Annularia*, and *Pinnularia*. The lycopods include *Lycopodites*, *Leptophleum*, *Lepidodendron*, *Psilophyton* (Fig. 386, especially characteristic), *Arthrostigma*, and *Bothrodendron* (*Cyclostigma*). The ferns belong to the genera *Archæopteris* (*Palæopteris*), *Neuropteris*, *Sphenopteris*, *Ancimites*,

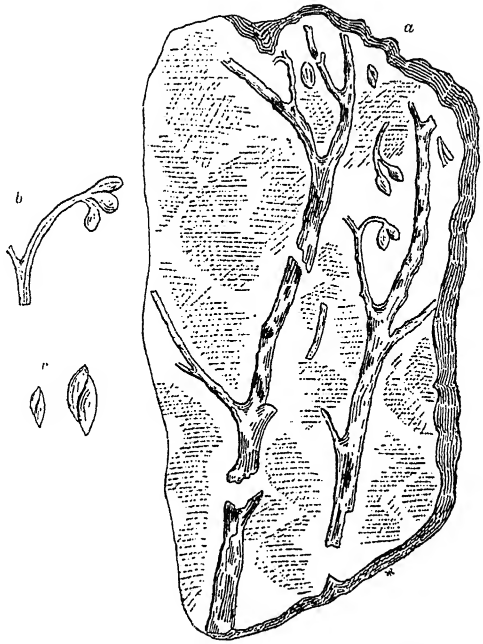


Fig. 386.—Psilophyton robustum, Dawson. Lower Old Red Sandstone, Perthshire. Drawn by Mr. R. Kidston.
a, specimen of the plant ½ nat. size; *b*, fructification; *c*, empty spore-cases.

Alethopteris, *Megalopteris*.[1] Higher forms of vegetation are represented by the Cordaitales, which include *Cordaites*, *Araucarioxylon* (*Dadoxylon*),[2] &c., and are now regarded as synthetic types, since they possess the characters of both the Coniferæ and Cycadofilicales. So abundant are the vegetable remains in certain districts of the Old Red Sandstone that in some layers they actually form thin seams of coal.

The interest of this flora is heightened by the discovery of the fact

[1] See note 3, p. 1013, on the plant-beds of St. John, New Brunswick, from which so rich a flora, supposed at first to be Devonian, was obtained.

[2] *Mem. Geol. Survey Canada*, 1871; *op. cit.* 1878; *Q. J. G. S.* 1881, p. 299; 'Acadian Geology,' 2nd edition.

that the primeval forests were not without the hum of insect life. Ancient relics of insect forms, which have been recovered from the Devonian strata of New Brunswick,[1] include both orthopterous and neuropterous wings, and have been regarded by Mr. Scudder of Boston as combining a remarkable union of characters now found in distinct orders of insects. In one fragment he observed a structure which he could only compare to the stridulating organ of some male *Orthoptera*. Another wing indicates the existence of a gigantic *Ephemera*, with a spread of wing extending to five inches. The Lower Helderberg rocks of New York, which by some geologists are placed in the Devonian system (p. 977), have furnished two genera of scorpions (*Palæophonus* and *Proscorpius*).

The existence of myriapods in the forests of this ancient period has been shown by Mr. B. N. Peach, who finds that the so-called *Kampecaris*, previously regarded as a larval form of isopod crustacean, really contains two genera (*Kampecaris*, *Archidesmus*) of chilognathous myriapods differing from other known forms, fossil and recent, in their less differentiated structure, each body segment being separate, and supplied with only one pair of walking legs.[2] There were also pulmoniferous shells, of which one species (*Strophites grandæva*, Dawson) occurs in the plant-beds of St. John, New Brunswick.[3]

The water-basins of the Old Red Sandstone might be supposed to have been, on the whole, singularly devoid of aquatic life, inasmuch as so large a proportion of the red sandy and marly strata is unfossiliferous. In some of the basins where the sediments are not red and sandy, it is evident that life was extremely abundant, as is shown, for example by the vast quantities of fossil fishes entombed in the grey bituminous flagstones of Caithness and Orkney. It may be observed also that where grey shales occur intercalated among the red sandstones and conglomerates they are often full of plant-remains, and may contain also ichthyolites and other fossils which are usually absent from the coarser red sediments. There would appear to have been occasions of sudden and widespread destruction of fish-life in the waters of the Old Red Sandstone, for platforms occur in which the remains are thickly crowded together, yet so entire that they could not have been transported from a distance, and must have been covered over with silt before they had time to decay and undergo much separation of their plates and scales (p. 828).

An interesting confirmation of the view that these basins were isolated is supplied by the occurrence of what is believed to be the oldest lacustrine or fluviatile mollusk yet known, *Amnigenia* (*Anodonta*, *Archanodon*) *Jukesii*. This shell has been found in the Upper Old Red Sandstone of Ireland and England associated with land-plants (*Archæopteris*, *Sphenopteris*, *Bothroden-*

[1] For a synopsis of all known species of fossil insects up to the year 1890, see *B. U.S. G. S.* No. 71, 1891.

[2] *Proc. Roy. Phys. Soc. Edin.* vii. (1882), p. 179.

[3] See the note on p. 1013 regarding the age of these plant-beds. If found in the Carboniferous portion, the shell mentioned in the text must be removed from the list of Devonian or Old Red Sandstone fossils.

dron, *Ulodendron*, *Stigmaria*, *Calamites*), fishes (*Coccosteus*) and arthropods (*Eurypterus*).[1] A closely allied species (*A. catskillensis*) has been met with in the Catskill formation of the United States, likewise accompanied

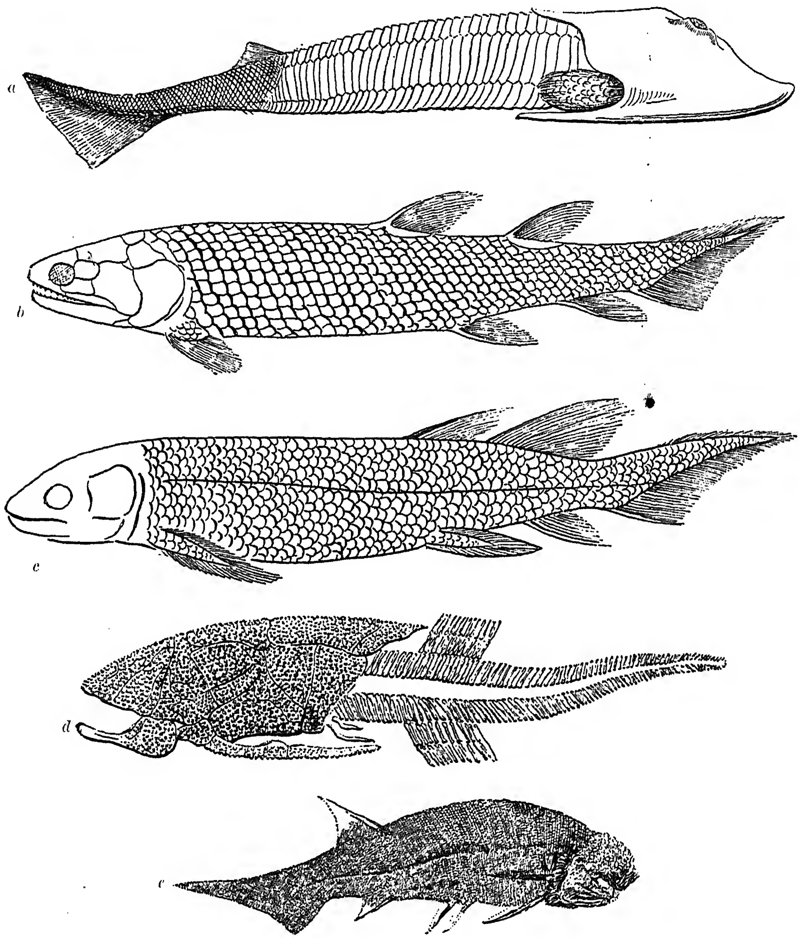


Fig. 387.—Lower Old Red Sandstone Fishes.

a, Cephalaspis Lyelli, Ag. (side view), restored by Professor Ray Lankester; *b*, Osteolepis microlepidotus, Sedgw. and Murch., restored by Dr. Traquair; *c*, Dipterus Valenciennesii, Sedgw. and Murch., from a sketch by Dr. Traquair; *d*, Coccosteus decipiens, Ag.; *e*, Mesacanthus (Acanthodes) Mitchelli, Eg., Forfarshire, from a sketch by Mr. B. N. Peach.

by land-plants and fishes (*Holonema*), while another species has been found in Russia. The shells resemble the modern *Unio*.

The fauna of the Old Red Sandstone consists pre-eminently of ostra-

[1] R. B. Newton, *Geol. Mag.* 1899, p. 245; J. M. Clarke, *Bull. New York State Mus.*, No. 49 (1901), p. 199.

coderms and fishes (Figs. 387, 388). Among these the *Pteraspis* survived for a while from Upper Silurian times. With it there lived other forms (*Holaspis*) and genera of the allied family of the Cephalaspidæ. Of the genus *Cephalaspis*, upwards of ten species are known, the largest of which (*C. magnifica*), from the Caithness flags, measures 12 inches in breadth. The ancient Dipnoi, which still survive in a few forms in some African and Australian rivers (*Protopterus*, *Ceratodus*), were represented in the lakes of the Lower Old Red Sandstone by the abundant *Dipterus*, and in those of the Upper by *Phaneropleuron*. The Elasmobranchs were represented by the acanthodians, distinguished by their strong spines, (*Mesacanthus* [*Acanthodes*], *Diplacanthus*, *Cheiracanthus*). Some of the most bizarre forms were such ostracoderms as the *Pterichthys* (Fig. 388), *Asterolepis*, and *Bothriolepis*. The order Crossopterygidæ, so remarkable for the central scaly lobe of their fins, and represented at the present time by *Polypterus*, swarmed in the waters, some of the most characteristic genera being *Tristichopterus*, *Gyroptichius*, *Glyptolepis*, *Osteolepis*, *Thursius*, and *Diplopterus*, which are found in the Caithness Flagstones of Scotland, and *Glyptopomus* and *Holoptychius*, which are characteristic of the Upper division of the system. The order Arthrodira, which comprises the family of the coccosteids, includes the type genus *Coccosteus*, *Phlyctænaspis*, and the gigantic *Homosteus* (*Asterolepis* of Hugh Miller, but not of Eichwald). This latter form appears to have been the largest fish of the period in the European area, its massive cuirass-like head-shield sometimes measuring twenty inches in length by sixteen in breadth. Ganoids were represented by some small sturgeon-like fishes (*Cheirolepis*) in the fauna of the earlier portion of the period in Scotland (Lake Orcadie), while in the Upper Old Red Sandstone there were selachians of the genera *Psammosteus* and *Cosmacanthus*.[1] The *Dinichthys* already referred to (p. 988) as occurring in the Devonian rocks of North America was probably one of the largest and most formidable of these early fishes. Its head alone, encased in strong plates, attained a length of three feet, and was armed with a powerful apparatus of teeth.

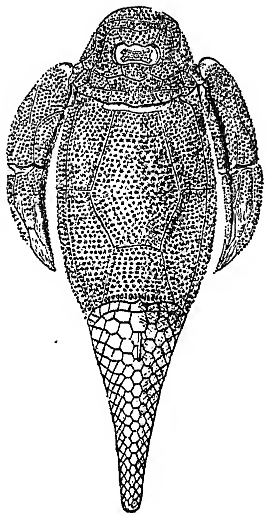


Fig. 388.—Pterichthys testudinarius, Ag. (cornutus, Ag.).

A few eurypterids are met with in the Old Red Sandstone, especially of the genera *Eurypterus* and *Pterygotus* (Fig. 384). The species of the former are small, but one of the latter, *P. anglicus*, is found in Scotland, which must have had a length of five or six feet. Other genera are *Eurypterella*, *Slimonia*, and *Stylonurus*. Phyllopods allied to the modern

[1] Traquair, *Geol. Mag.* 1888, p. 507, and "The extinct vertebrata of the Moray Firth area" in Harvey Brown and Buckley's 'Vertebrate Fauna of the Moray Basin,' 1896. M. Lohest, *Ann. Soc. Géol. Belg.* xv. (1888), p. 112. Whiteaves, *Canad. Nat.* x. Nos. 1, 2 (1881).

brackish-water *Estheria* abound in the Caithness flagstones, in north-west Russia and in the Catskill group (New York). Ostracods (*Aparchites*, *Isochilina*, *Beyrichia*, or *Drepanella?*) occur in Scotland. Phyllocarid genera are found, especially in the upper part of the system, in the United States (*Echinocaris*, *Pephricaris*, *Eleutherocaris*, *Elymocaris*, *Tropidocaris*).

§ 2. Local Development.

Britain.—Murchison, who strongly advocated the opinion that the Old Red Sandstone and Devonian rocks represent different geographical conditions of the same period, and who had with satisfaction seen the adoption of the Devonian classification by Continental geologists, endeavoured to trace in the Old Red Sandstone of Britain a threefold division, like that which had been accepted for the Devonian system. He accordingly arranged the formations as in the subjoined table :—

Old Red Sandstone as classified by Murchison.	Upper.	Yellow and red sandstones and conglomerates (*Bothriolepis* [formerly *Pterichthys*] *major*, *Holoptychius nobilissimus*, &c.) = Dura Den beds.
	Middle.	Grey and blue calcareous and bituminous flagstones, limestones, and red sandstones and conglomerates (*Dipterus*, *Osteolepis*, *Homosteus*, *Mesacanthus*, *Pterichthys*, &c.) = Caithness flags.
	Lower.	Red and purple sandstones, grey sandy flagstones, and coarse conglomerates (*Cephalaspis*, *Pteraspis*, *Pterygotus*) = Arbroath flags.

It is important to observe that in no district can these three subdivisions be found together, and that the so-called "middle" formation occurs only in one region—the north of Scotland. The classification, therefore, does not rest upon any actually ascertained stratigraphical sequence, but on an inference from the organic remains. The value of this inference will be estimated a little farther on. All that can be affirmed from the observed stratigraphy is that a great physical and palæontological break can everywhere be traced in the Old Red Sandstone of Scotland, dividing it into two completely distinct series.[1] A similar hiatus will not improbably be discovered in the Old Red Sandstone of South Wales.

As above remarked, the Old Red Sandstone, where its strata are really red, is, like other masses of red deposits, singularly barren of organic remains. The physical conditions under which the precipitation of iron-oxide took place are not easily explained, but were evidently unfavourable for the development, or at least for the fossilisation, of animal life in the same waters. Ramsay connected the occurrence of such red formations with the existence of salt lakes, from the bitter waters of which not only iron-oxide but often rock-salt, magnesian limestone, and gypsum were thrown down.[2] He pointed also to the presence of land-plants, footprints of amphibia (in Permian and later formations) and other indications of terrestrial surfaces while truly marine organisms are either found in a stunted condition or are absent altogether. We have seen that where the strata of the Old Red Sandstone, losing their red colour and ferruginous character, assume grey or yellow tints and pass into a calcareous or argillaceous condition, they not infrequently become fossiliferous. At the same time, it is worthy of remark that red conglomerates, which might be supposed little likely to contain organic remains, are occasionally found to be full of detached scales, plates, and bones of fishes.

[1] A. G., *Q. J. G. S.* vol. xviii. (1860), p. 312.

[2] Professor Gosselet contends that the precipitation of iron might quite well have taken place in the sea, and he cites the case of the Devonian basin of Dinant, where the same beds are in one part red and barren of organic remains, and in another part of the same area are of the usual colours, and are full of marine fossils. But the red colour of the Old Red Sandstone is general, and is accompanied with other proofs of isolation in basins (p. 1000).

The Old Red Sandstone of Britain, according to the author's researches, consists of two subdivisions, the lower of which passes down conformably into the Upper Silurian deposits, the upper shading off in the same manner into the base of the Carboniferous system, while they are separated from each other by an unconformability.

1. LOWER.—Red sandstones, conglomerates, flagstones, and associated igneous rocks, passing in some places conformably down into Upper Silurian formations, elsewhere resting unconformably on Dalradian or other older rocks—*Pachytheca, Parka, Kampecaris, Eurypterus, Pterygotus, Cephalaspis, Mesacanthus, Ischnacanthus* (*Diplacanthus*), *Climatius, Thelodus,* &c.

In a memoir on the Old Red Sandstone of Western Europe, the author proposed short names for the different detached basins in which the Lower Old Red Sandstone was accumulated.[1] The most southerly of these (the Welsh Lake) lies in the Silurian region extending from Shropshire into South Wales. Here the uppermost parts of the Silurian system graduate into red strata, not less than 10,000 feet thick, which in turn pass up conformably into the base of the Carboniferous system. This vast accumulation of red rocks consists in its lower portions of red and green shales and flagstones, with some white sandstones and thin cornstones; in the central and chief division, of red and green spotted sandy marls and clays, with red sandstones and cornstones; in the higher parts, of grey, red, chocolate-coloured, and yellow sandstones, with bands of conglomerate. No unconformability has yet been proved in any part of this series of rocks, though, from the observations of De la Beche and Jukes, it may be suspected that the higher strata, which graduate upwards into the Carboniferous formations, are separated from the underlying portions of the Old Red Sandstone by a distinct discordance.[2]

Although, as a whole, barren of organic remains, these red rocks have here and there, more particularly in the calcareous zones, yielded fragments of fishes and crustaceans. In their lower and central portions remains of *Cephalaspis, Didymaspis, Pteraspis,* and *Cyathaspis* have been found, together with eurypterids of the genera *Stylonurus, Pterygotus,* the crustacean *Prearcturus,* and obscure traces of plants. The upper yellow and red sandstones contain none of the cephalaspid fishes, which are there replaced by *Bothriolepis* and *Holoptychius,* together with *Amnigenia* (*Anodonta*) and distinct impressions of land-plants. In some of the higher parts of the Old Red Sandstone of South Wales and Shropshire, *Serpula* and *Conularia* occur, but these are exceptional cases, and point to the advent of the Carboniferous marine fauna, which doubtless existed outside the British area before it spread over the site of the Old Red Sandstone basins.

It is in Scotland[3] that the Old Red Sandstone shows the most complete and varied development, alike in physical structure and in organic contents. Throughout that country the system is found to be distributed in distinct basins of deposit, in each of which, where fully developed, it consists of two well-marked groups of strata,

[1] A. G., *Trans. Roy. Soc. Edin.* vol. xxviii. (1879).

[2] De la Beche, *Mem. Geol. Surv.* vol. i. (1846), p. 50. J. B. Jukes, 'Letters, &c.' (1871), p. 508; letter to A. C. Ramsay, dated 1857. Symonds, 'Records of the Rocks' (1872). Hughes, *Brit. Assoc. Rep.* (1875), sects. p. 70. The Geological Survey is now engaged in revising the maps of South Wales and may succeed in determining the detailed stratigraphy of the Old Red Sandstone in that region which, in its western part, is somewhat complicated. Up to the present time, however, no definite break in the stratigraphical sequence of the formation has been detected. *Summary of Progress* for 1901.

[3] See Agassiz, 'Poissons du Vieux Grès Rouge.' Hugh Miller's 'Old Red Sandstone,' and 'Footprints of the Creator.' J. Anderson's 'Dura Den.' Huxley, *Decade* x. *of Mem. Geol. Surv.* 1861. *Explanations Geol. Surv. Scotland,* sheets 14, 15, 23, 24, 32, 33, 34; *Geol. Surv. Memoirs* on "Central Fife," 1900, and "East Fife," 1902; author's memoirs cited on this and the previous page, and 'Ancient Volcanoes of Great Britain,' Book V.

separated from each other by a strong unconformability and a complete break in the succession of organic remains. There is sufficient diversity of lithological and palæontological characters to indicate that these several areas were on the whole distinct basins, separated both from each other and from the sea. The interval between the Lower and Upper Old Red Sandstone was so protracted, and the geographical changes accomplished during it were so extensive, that the basins in which the late parts of the system were deposited only partially corresponded with those of the older lakes.

Of the basins in which the Lower division of the system was deposited the most important (Lake Caledonia) occupies the central valley, between the base of the Highland mountains and the Uplands of the southern counties. On the north-east, it presents a series of noble cliff-sections along the coast-line from Stonehaven to the mouth of the Tay. On the south-west it ranges by the island of Arran and the south of Cantyre across St. George's Channel into Ireland, where it runs almost to the western seaboard, flanked on the north, as in Scotland, by hills of crystalline rocks, and on the south chiefly by a Silurian belt. Both divisions of the Old Red Sandstone are here typically seen. The lower series of deposits attains a maximum depth of perhaps 20,000 feet, and everywhere presents traces of shallow-water conditions. The accumulation of so great a thickness of sediment can only be explained on the supposition that the subterranean movements, which at first ridged up the Silurian sea-floor into land, enclosing separate basins, continued to deepen these basins, until eventually, enormous masses of sediment had slowly gathered in them. This massive series of deposits passes down conformably in Lanarkshire into Upper Silurian rocks; elsewhere its base is concealed by later formations, or by the unconformability with which different horizons rest upon the older rocks. Covered unconformably by every rock younger than itself, it consists of reddish-brown or chocolate-coloured, grey, and yellow sandstones, red shales, grey flagstones, coarse conglomerates, with occasional bands of limestone and cornstone. The grey flagstones and thin grey and olive shales and "calmstones" are almost confined to Forfarshire, in the north-east part of the basin, and are known as the "Arbroath flags." One of the most marked lithological features in this central Scottish basin is the occurrence in it of extensive masses of interbedded volcanic rocks. These, consisting of andesites, dacites, diabases, agglomerates, and tuffs, attain a thickness of more than 6000 feet, and form important chains of hills, as in the Pentland, Ochil, and Sidlaw ranges. They lie several thousand feet above the base of the system, and are regularly interstratified with bands of the ordinary sedimentary strata. They point to the outburst of numerous volcanic vents along the lake or inland sea in which the Lower Old Red Sandstone of Central Scotland was laid down; and their disposition shows that these vents ranged themselves in lines or linear groups, parallel with the general trend of the great central valley. The fact that the igneous rocks are succeeded by thousands of feet of sandstones, shales, and conglomerates, without any intercalation of lava or tuff, proves that the volcanic episode in the history of the lake came to a close long before the lake itself disappeared.[1] As a rule, the deposits of this basin are singularly unfossiliferous, though some portions of them, particularly in the Forfarshire (Arbroath) flagstone group, have proved rich in remains of crustaceans and fishes. Nine or more species of crustaceans have been obtained, chiefly eurypterids, but including one or two phyllopods. The large pterygotus (*P. anglicus*) is especially characteristic, and must have attained a great size, for some of the individuals indicate a length of 6 feet, with a breadth of 1½ feet. There occur also a smaller species (*P. minor*), two *Eurypteri* and three species of *Stylonurus*. Upwards of twenty species of fishes have been obtained, chiefly from the Arbroath flags, belonging to the groups Acanthodii and Ostracodermi (Fig. 387). One of the most abundant forms is the little *Mesacanthus* (*Acanthodes*) *Mitchelli*. Another common fish is *Ischnacanthus* (*Diplacanthus*) *gracilis*. There occur

[1] A. G., Presidential Address, *Q. J. G. S.* 1892, p. 62 *seq.* This volcanic history is more fully discussed in 'Ancient Volcanoes of Great Britain,' Book v.

also *Climatius scutiger*, *C. reticulatus*, *C. uncinatus*, *C. Macnicoli*, *C. grandis*, *C. gracilis*, *Parexus incurvus*, *Cephalaspis Lyellii*, *Pteraspis Mitchelli*, and the curious shark-like genus *Thelodus*, which survived from Upper Silurian time. Some of the sandstones and shales are crowded with indistinctly preserved vegetation (*Pachytheca*, &c.), occasionally in sufficient quantity to form thin laminæ of coal. The egg-like impressions known as *Parka decipiens* and referred to on p. 1001, also abound in some layers. In Forfarshire, the surfaces of the shaly flagstones are now and then covered with linear grass-like plants, like the sedgy vegetation of a lake or marsh. In Perthshire, certain layers occur, chiefly made up of compressed stems of *Psilophyton* (Fig. 386). The adjoining land was doubtless clothed with a flora in large measure lycopodiaceous.

On the northern side of the Highlands lies another still larger basin (Lake Orcadie), but only a portion of it emerges above the sea. Skirting the slopes of the mountains along the Moray Firth and the east of Ross and Sutherland, it stretches through Caithness and the Orkney Islands to the southern part of the Shetland Group. It may possibly have been at one time continued as far as the Sognefjord and Dalsfjord in Norway, where red conglomerates like those of the north of Scotland occur. It may even have ranged eastwards into Russia, or at least have had a water-channel connecting it with that region, for, as already stated, some of its most characteristic fishes are found also among the Russian Devonian formations. Its strata are typically developed in Caithness, where they consist chiefly of the well-known dark-grey bituminous and calcareous flagstones of commerce. These lie unconformably upon various crystalline schists, granites, &c., and must have been deposited on the uneven bottom of a sinking basin, seeing that occasionally even some of the higher platforms are found resting against the more ancient rocks. The lower zones consist of red sandstones and conglomerates, which graduate upward into the flagstones. Other red sandstones, however, supervene in the higher parts of the system. The total depth of the series in Caithness has been estimated at upwards of 16,000 feet. Murchison was the first to attempt the correlation of the Caithness flagstones with the Old Red Sandstone of the rest of Britain. Founding upon the absence from these northern rocks of the cephalaspidean fishes characteristic of the admitted Lower Old Red Sandstone in the south of Scotland and in Wales and Shropshire, upon the presence of numerous genera of fishes not known to occur elsewhere in the true Lower Old Red Sandstone, and upon the discovery of a *Pterygotus* in the basement red sandy group of strata, he concluded that the massive flagstone series of Caithness could not be classed with the Lower Old Red Sandstone, but must be of younger date. He supposed the red sandstones, conglomerates, and shales at the base, with their *Pterygotus*, to represent the true Lower Old Red Sandstone, while the great flagstone series with its distinctive fishes was made into a middle division, answering in some of its ichthyolitic contents to the Middle Devonian rocks of the Continent. It must be admitted that the fauna of Lake Orcadie is unlike that of Lake Caledonia, while the identity of some of the northern genera with those elsewhere found in middle or even upper Devonian horizons is so far in favour of Murchison's view. On the other hand, considered from the tectonic side it is difficult to believe that the similar Old Red accumulations on the two sides of the Grampians, now only a few miles apart, can belong to widely different periods. Long continued isolation in separate basins would lead to great changes in the faunas of these areas, and the conditions for biological development, if we may judge from the abundance of the fish remains, were more favourable in the northern than in the southern waters. A few of the genera specially distinctive of the Lower Old Red Sandstone do occur in the Moray Firth area (*Pterygotus*, *Cephalaspis*, *Mesacanthus*, and perhaps *Parexus*). Moreover, the Lake Orcadie flagstones and fish-beds are overlain unconformably by the undoubted Upper Old Red Sandstone, with its characteristic fishes, so that they occupy a stratigraphical position identical with that of the unquestioned Lower Old Red Sandstone on the south side of the Highlands. More than sixty species of fishes have been obtained from the Old Red Sandstone of the north of Scotland. Among these, the genera

Cheiracanthus, *Cheirolepis*, *Coccosteus*, *Diplacanthus*, *Diplopterus*, *Dipterus*, *Glyptolepis*, *Gyroptychius*, *Homacanthus*, *Homosteus*, *Mesacanthus*, *Osteolepis*, *Palæospondylus*, *Pterichthys* (several species), *Rhadinacanthus* and *Thursius* are specially characteristic. Some of the shales are crowded with the little phyllopod crustacean *Estheria membranacea*, and the largest species of *Cephalaspis* (*C. magnifica*) comes from this basin. Land-plants abound, especially in the higher groups of the flagstones, where forms of *Psilophyton*, *Lepidodendron*, *Stigmaria*, *Sigillaria* (?), *Calamites* and *Cyclopteris*, as well as other genera, occur. In the Shetland Islands, traces of abundant contemporaneous volcanic rocks have been observed.[1] These, with the exception of two trifling examples in the region of the Moray Firth, are the only known instances of volcanic action in the Lower Old Red Sandstone of Lake Orcadie.

A third basin in which the Lower Old Red Sandstone was deposited extends through the district of Lorne in the west of Argyllshire. The rocks in that area consist in large measure of andesitic and trachytic lavas and tuffs, but with some underlying and intercalated shales, sandstones, and conglomerates. From these strata an interesting series of organic remains has been obtained near Oban, including a new species of *Cephalaspis* (*C. lornensis*), *Mesacanthus*, *Thelodus* (?); several genera of ostracods (*Aparchites*, *Isochilina*, and *Beyrichia* or *Drepanella* ?), *Pterygotus* (like *P. Anglicus*); two species of chilognathous myriapods (*Kampecaris* and *Archidesmus*) and plant-remains, some of which are allied to *Psilophyton*.[2] The researches of the Geological Survey, which have brought these organisms to light, have also determined that the younger granites of this region have invaded and altered various members of the Lower Old Red Sandstone, and thus that some portions of the great intrusive bosses of the Highlands are not older, but may be younger, than the Lower Old Red Sandstone.[3]

Another basin of accumulation of the Lower Old Red Sandstone lies in the east of Berwickshire, and includes the Cheviot Hills. Its materials are again largely of volcanic origin (andesitic lavas and tuffs, &c.), but they include strata containing remains of plants and *Pterygotus*. It is interesting to notice that in this tract also the volcanic rocks have been invaded by a granitic boss. Not improbably here and in the Highlands these intrusive masses were connected with the closing phases of the volcanic period, like the great cones of granophyre and granite among the Tertiary basalts of the inner Hebrides.[4]

2. UPPER.—This division consists of red sandstones, deep-red clays or marls, conglomerates, and breccias, the sandstones passing into yellow or even white. These strata, wherever their stratigraphical relations can be distinctly traced, lie unconformably upon every formation older than themselves, including the Lower Old Red Sandstone, while, on the other hand, they pass up conformably into the Carboniferous rocks above. As already remarked, they were deposited in basins, which only partially corresponded with those wherein the Lower Old Red Sandstone had been laid down. Studied from the side of the underlying formations, they seem naturally to form part of the Old Red Sandstone, since they agree with it in general lithological character, and also in containing some distinctively Old Red Sandstone genera of fishes, such as *Bothriolepis*, *Coccosteus*, and *Holoptychius;* though, approached from the upper or Carboniferous

[1] A. G., *Trans. Roy. Soc. Edin.* xxviii. (1878), p. 345; Presidential Address, *Q. J. G. S.* xlviii. (1892), p. 94; 'Ancient Volcanoes of Great Britain,' chap. xxi. (1898), pp. 383, 865. Peach and Horne, *Proc. Roy. Phys. Soc. Edin.* v. (1880); *Trans. Roy. Soc. Edin.* xxxii. (1884), p. 359. J. S. Flett, *op. cit.* xxxix.

[2] 'Ancient Volcanoes of Great Britain,' i. p. 341; *Summary of Progress of Geol. Surv.* for the years 1897-1901; H. Kynaston, *Trans. Edin. Geol. Soc.* viii. (1900), p. 87.

[3] See especially the work of Mr. Kynaston in *Summary of Progress* for 1901 and previous years.

[4] C. T. Clough, "Cheviot Hills," *Geol. Surv. Mem.* Sheet 108 N.E. (1888). J. J. H. Teall, *Geol. Mag.* 1883. 'Ancient Volcanoes of Great Britain,' i. p. 336.

direction, they might rather be assumed as the natural sandy base of that system into which they insensibly graduate. On the whole, they are remarkably barren of organic remains, though in some localities (Dura Den in Fife, Lauderdale) they have yielded a number of genera and species of fishes, crowded profusely through the sandstone, as if the individuals had been suddenly killed and rapidly covered over with sediment. Among the distinctive fossils of the Upper Old Red Sandstone are species of *Asterolepis*, *Bothriolepis* (formerly confused with *Pterichthys*), *Coccosteus*, *Conchodus*, *Cosmacanthus*, *Glyptopomus*, *Gyroptychius*, *Holoptychius* (four or more species), *Phanero-pleuron*, *Phyllolepis*, *Polyplocodus* and *Psammosteus*.

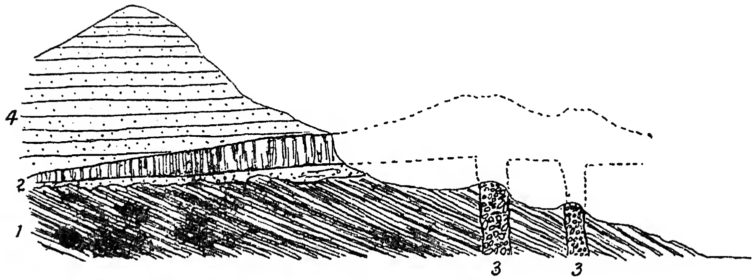


Fig. 389.—Section showing the relation of the two divisions of the Old Red Sandstone in Hoy, Orkney Islands.

1, Caithness flagstones; 2, zone of lavas and tuffs lying on red sandstones and conglomerates; 3, two volcanic necks marking the sites of eruptive vents; 4, Upper Old Red Sandstone, with a volcanic zone near its base.

This subdivision is well developed in Central Scotland (Fife, Lothians, Berwickshire, Ayrshire), where it forms the conformable base of the Carboniferous system and lies transgressively on older formations. In the north of Scotland, along the lowlands bordering the Moray Firth, yellow and red sandstones, containing characteristic Upper Old Red Sandstone fishes, are well developed. In the island of Hoy (Orkney) they can be seen to lie unconformably on the Caithness flags and to include some intercalated diabase and tuff, which mark the only known volcanic episode in the Upper Old Red Sandstone of England or Scotland (Fig. 389). In these northern tracts, the same relation as in the central counties is thus traceable between the two divisions of the system.[1]

In the north of England sandstones and conglomerates representing the ordinary type of the Upper Old Red Sandstone emerge from underneath the Carboniferous formations, and lie unconformably on Silurian rocks and Lower Old Red Sandstone. Some of the brecciated conglomerates have much resemblance to glacial detritus, and it was suggested by Ramsay that they have been connected with contemporaneous ice-action.[2] Such are the breccias of the Lammermuir Hills, and those which show themselves here and there from under the overlying mass of Carboniferous strata that

[1] A. G., *Trans. Roy. Soc. Edin.* xxviii. (1878), p. 405; 'Ancient Volcanoes of Great Britain,' i. p. 350.

[2] The examples of supposed glacial striæ on the pebbles in these breccias may be merely frictional markings connected with faults or internal movements of the rocks. But the forms of the pebbles, their moraine-like unstratified or rudely-stratified accumulation, and the occurrence of aggregated lumps of breccia in the midst of fine sandstone strongly remind one of the familiar features of true glacial deposits. Compare H. Reusch, on similar evidence from the Palæozoic rocks of Norway, *Norges Geol. Undersög. Aarbog.* 1891, and A. Strahan *Q. J. G. S.* liii. (1897), p. 137.

flank the Silurian hills of Cumberland and Westmoreland. Red conglomerates and sandstones appear interruptedly at the base of the Carboniferous rocks, even as far as Flintshire and Anglesey. They are commonly classed as Old Red Sandstone, but merely from their position and lithological character, no organic remains having been found in them. They may therefore, in part at least, belong to the Carboniferous system, having been deposited on different successive horizons during the gradual depression of the land. In South Wales and the border counties of England, as already stated, the Carboniferous series passes down conformably into the Upper Old Red Sandstone, which cannot at present be separated from older parts of the system. In Devonshire, at Barnstaple, Pilton, Marwood, and Baggy Point, certain sandstones, shales, and limestones (already referred to in the account of the Devonian rocks) graduate upward into the base of the Carboniferous system, and appear to represent the Upper Old Red Sandstone of the rest of Britain. They contain land plants and also many marine fossils, some of which are common Carboniferous forms.

The Old Red Sandstone attains a great development in the south and south-west of Ireland. The thick "Dingle Beds" and "Glengariff grits" pass down into Upper Silurian strata, and no doubt represent the Lower Old Red Sandstone of Scotland. They are succeeded in Kerry by red sandstones which cover them unconformably, and resemble the ordinary Upper Old Red Sandstone of Scotland. In Cork and the south-east of Ireland they are followed by the pale sandstones and shaly flagstones known as the "Kiltorcan beds," with apparently a perfect conformability. The Kiltorcan beds (which pass up conformably into the Carboniferous Slate) have yielded a few fishes (*Bothriolepis*, *Coccosteus*, *Glyptolepis*), some merostomata (*Belinurus*, *Pterygotus*), the unio-like *Amnigenia* (*Anodonta*) *Jukesii*, and a number of ferns and other land-plants (*Archaeopteris*, *Sphenopteris*, *Sagenaria* (*Cyclostigma*), and those described under the name of *Knorria*).[1]

Norway, Arctic Regions. On the continent of Europe the Old Red Sandstone type can hardly be said to occur. Some outliers of red sandstone and conglomerate (p. 1009) in northern and western Norway reach a thickness of 1000 to 1200 feet. Near Christiania, they follow the Silurian strata like the Old Red Sandstone, but as yet have yielded no fossils, so that, as they pass up into no younger formation, their geological horizon cannot be certainly fixed. The Devonian rocks of Russia have been above referred to as presenting a union of the two types of this part of the geological series. The extension of the land of the Old Red Sandstone period, with its characteristic flora, far north within the Arctic circle is indicated by the discoveries made at Bear Island (lat. 70° 30′ N.) between the coast of Norway and Spitzbergen. Certain seams of coal and coaly shale occur at that locality, underlying beds of Carboniferous Limestone and overlying some yellow dolomite, calcareous shale, and red shales. They were assigned by Heer to the Carboniferous series, but were regarded by Dawson as Devonian. They may be correlated with the Upper Old Red Sandstone of Britain. Of the eighteen species enumerated by Heer, only three were stated by him to be peculiar to the locality, while among the others were some widely-diffused forms: *Asterocalamites scrobiculatus* (*Calamites radiatus*), *C. transitionis*, *Archaeopteris roemeriana*, *Sphenopteris Schimperi*, *Cardiopteris frondosa*, *Lepidodendron Veltheimianum*. More recently other forms have been found, including the characteristic fern *Archaeopteris hibernica* and a few other species, *Bothrodendron kiltorkense*, species of *Cephalotheca*, *Cyclostigma*, *Knorria*, *Macrostachya*, *Pteridorachis*, *Sphenopteridium*, *Stigmaria*, &c., together with the typical genus of Upper Old Red Sandstone fish, *Holoptychius*.[2]

[1] Professor Hull, *Q. J. G. S.* xxxv. xxxvi.; *Trans. Roy. Dublin Soc.* (new ser.) i. p. 135 (1880); *Explanations of the Geol. Survey, Ireland*, sheets 167, &c., 187, &c. J. Nolan, *Q. J. G. S.* 1880, p. 529. Kinahan, *Trans. Geol. Soc. Edin.* 1882, p. 152. The south of Ireland formed another of the basins in which the Lower Old Red Sandstone was accumulated.

[2] Heer, *Q. J. G. S.* xxviii. p. 161. Dawson, *op. cit.* xxix. p. 24. A. G. Nathorst, 'Zur

Still farther north more complete evidence of the northward extension of the Old Red Sandstone has been found in Spitzbergen, where both the Lower and Upper divisions of the system are represented by their characteristic fossils. The Lower section is marked in the red micaceous sandstones and cornstones of Dickson Bay by the occurrence of *Pteraspis*, *Cephalaspis*, *Acanthaspis*, and other genera, while the Upper is indicated by the strata of Mimers Valley, containing *Psammosteus*, *Asteroplax*, *Onychodus* and teeth, scales, and plates, which may be referable to *Holoptychius*, *Sauripterus*, and other forms.[1]

North America.—It is interesting to observe that in North America representatives occur of the two divergent Devonian and Old Red Sandstone types of Europe. The American Devonian facies has already been referred to. On the eastern side of the ancient pre-Cambrian and Silurian ridge, which, stretching southwards from Canada, separated in early Palæozoic time the great interior basin from the Atlantic slopes, we find the Devonian rocks of New York, Pennsylvania, and the interior represented in New Brunswick and Nova Scotia by a totally different series of deposits. The contrast strikingly recalls that presented by the Old Red Sandstone of the north of Scotland and the Devonian rocks of North Germany. On the south side of the St. Lawrence, the coast of Gaspé shows rocks of the so-called "Quebec group" unconformably overlain by grey limestones with green and red shales, attaining, according to Logan, a total thickness of about 2000 feet,[2] and in some bands replete with Upper Silurian fossils. They are conformably followed by a vast arenaceous series of deposits termed the Gaspé Sandstones, to which the careful measurements of Logan and his colleagues of the Canadian Geological Survey assign a depth of 7036 feet. This formation consists of grey and drab-coloured sandstones, with occasional grey shales and bands of massive conglomerate. Similar rocks reappear along the southern coast of New Brunswick, where they attain a depth of 9500 feet, and again on the opposite side of the Bay of Fundy. The researches of Sir J. W. Dawson, already referred to, have made known the remarkable flora of these rocks.[3] Some of the same plants are said to occur in the Devonian rocks to the west of the Archæan ridge, and thus to afford a presumption of the contemporaneity of the deposits on the two sides. Associated with the vegetation are the remains of insects, myriapods, arachnoids, and a scorpion, together with two species of land-snails. In recent years a considerable number of fossil fishes have been obtained from two localities in New Brunswick, which prove beyond question that the rocks containing them represent the Old Red Sandstone of Europe. In the lists, as published, there is a commingling of both Lower and Upper forms. From Campbellton, at the head of the Bay of Chaleur, have been obtained *Cephalaspis* (two species), *Phlyctænaspis*,

paläozoischen Flora der arktischen Zone,' *Svensk. Vet. Akad. Handling.* xxvi. No. 4 (1894); 'Zur oberdevonischen Flora von Bären-Insel,' *op. cit.* xxxvi. No. 3 (1902); *Bull. Geol. Inst. Upsala*, No. 8, iv. Part ii. (1899).

[1] E. Ray Lankester, *Svensk. Akad. Handling.* xx. (1884), No. 9. A. S. Woodward, *Ann. Mag. Nat. Hist.* viii. (1891).

[2] 'Geology of Canada,' p. 393. The probable limits of the lake or lagoon in which the Oneonta sediments were laid down (with their *Estheria membranacea* and *Amnigenia catskillensis*) are being traced by some of the geologists of New York State, who have suggested a connection between that sheet of water and the lakes of Nova Scotia and Gaspé. Papers by Messrs. J. M. Clarke, E. O. Ulrich, and C. Schuchert in recent *Bulletins* of the New York State Museum (1900-2).

[3] "Fossil Plants of the Devonian and Silurian Formations of Canada," *Geol. Surv. Canada*, 1871. There appears, however, to be some difference of opinion as to the stratigraphical position of some part at least of the flora which is found at St. John, New Brunswick. Regarded by Dawson and others as undoubtedly Devonian, it has more recently been claimed as Carboniferous, and the strata containing it to be the equivalents of the Riversdale series of Nova Scotia. See J. F. Whiteaves, Address to Sect. E. *Amer. Assoc.* 1899.

Gyracanthus, *Cheiracanthus*, *Acanthodes*, *Protodus*, *Diplodus*, together with *Psilophyton*, *Arthrostigma*, *Leptophlæum*, *Cordaites*, and *Prototaxites*. This assemblage resembles that of the Caithness flags. From Scaumenac Bay comes another species of *Cephalaspis*, also *Acanthodes*, *Bothriolepis*, *Scaumenacia* (*Phaneropleuron*), *Glyptolepis*, and *Eusthenopteron* (allied to the *Tristichopterus* of Caithness). Here *Cephalaspis*, which in Europe is a characteristic genus of the older part of the system, is placed with *Bothriolepis*, which is only found in the younger part. Some more detailed stratigraphical research in this region would seem to be desirable.[1]

Section iv. Carboniferous.

§ 1. General Characters.

This great system of rocks has received its name from the seams of coal which form one of its distinguishing characters in many parts of the world. Both in Europe and America it may be seen passing down conformably into the Devonian and Old Red Sandstone. So insensible indeed is the gradation in many consecutive sections where the two systems join each other that no sharp line can there be drawn between them. This stratigraphical passage is likewise frequently associated with a corresponding commingling of organic remains, either by the ascent of undoubted Devonian species into the lower parts of the Carboniferous series, or by the appearance in the Upper Devonian beds of species which attained their maximum development in Carboniferous times. Hence there can be no doubt as to the true place of the Carboniferous system in the geological record. In some places, however, the higher members of this system are found resting unconformably upon Devonian or older rocks, so that local disturbances of considerable magnitude occurred before or during the Carboniferous period. It is deserving of notice that Carboniferous rocks are very generally arranged in basin-shaped areas, many of which have been wholly or partially overspread unconformably by later formations. This disposition, so well seen in Europe, and particularly in the central and western half of the continent, has in some cases been caused merely by the plication and subsequent extensive denudation of what were originally wide continuous sheets of rock, as may be observed in the British Isles. But the remarkable small scattered coal-basins of France and Central Germany were probably from the first isolated areas of deposit, though they have suffered, in some cases very greatly, from subsequent plication and denudation. In Russia, and still more in China and western North America, Carboniferous rocks cover thousands of square miles in horizontal or only very gently undulating sheets.

Rocks.—The materials of which the Carboniferous system is built up differ considerably in different regions; but two facies of sedimentation have a wide development. In one of these, the marine type, limestones form the prevailing rocks, and are often visibly made up of

[1] See the Address of Mr. Whiteaves just cited, and the references there given.

organic remains, chiefly encrinites, corals, foraminifera, and mollusks. According to Dupont's researches in the Carboniferous Limestone of Belgium there are two main types of limestone: (1) the massive limestones formed by reef-building corals and coralloid animals, and disposed in fringing reefs or dispersed atolls, according to their nearness to or distance from the coast of the time; and (2) the detritic limestones, mainly consisting either of an aggregation of crinoid stems or of coral-débris, and often stretching in extensive sheets like sandstone or shale.[1] The limestones of both types assume a compact homogeneous character, with black, grey, white, or mottled colours, and are occasionally largely quarried as marble. Local developments of oolitic structure occur among them. They also assume in some places a yellowish, dull, finely granular aspect and more or less dolomitic composition. They occur in beds, sometimes as in Central England, Ireland, and Belgium, piled over each other for a depth of hundreds of feet, and in Utah for several thousand feet, with little or no intercalation of other material than limestone. The limestones frequently contain irregular nodules of a white, grey, or black flinty chert (phtanite), which, presenting a close resemblance to the flints of the chalk, occur in certain beds or layers of rock, sometimes in numbers sufficient to form of themselves tolerably distinct strata.[2] These concretions are associated with the organisms of the rock, some of which, completely silicified and beautifully preserved, may be found imbedded in the chert. Dolomite, usually of a dull yellowish colour, granular texture, and rough feel, occurs both in beds regularly interstratified with the limestones and also in broad wall-like masses running through the limestones. In the latter cases, it is evident that the limestone has been changed into dolomite along lines of joint; in the former, the dolomite may be due to contemporaneous alteration of the original calcareous deposit by the magnesian salts of sea-water, as already explained (pp. 426, 530). Traced to a distance, the limestones are often found to grow thinner, and to be separated by increasing thicknesses of shale, or to become more and more argillaceous and to pass eventually into shale. The shales, too, are often largely calcareous, and charged with fossils; but in some places assume dark colours, become more thoroughly argillaceous, and contain, besides carbonaceous matter, an impregnation of pyrites or marcasite. Where the marine Carboniferous type dies out, the shales may pass into coal or ironstone, associated with sandstones and clays. In Britain, abundant contemporaneous volcanic rocks are preserved in the Carboniferous Limestone series.

The second facies of sedimentation points to deposit in shallow lagoons, which at first were replenished from the sea, but afterwards appear to have been brackish and then fresh, or in lakes into which coarse and fine detritus as well as vegetation and animal remains were washed from neighbouring land. The most abundant strata of this type are sandstones, which, presenting every gradation of fineness of grain up

[1] *Bull. Acad. Roy. Belg.* (3) v. 1883, No. 2. See also the papers on reef-knolls by Mr. Tiddeman, cited p. 1041.

[2] Renard, *Bull. Acad. Roy. Belg.* (2) xlvi. p. 9.

to pebbly grits, and even (near former shore-lines) conglomerates, are commonly yellow, grey, or white in colour, well-bedded, sometimes micaceous and fissile, sometimes compact; often full of streaks or layers of coaly matter. Besides the existence of pebbly grits and conglomerates pointing to shallow water and comparatively strong currents of transport, there occur in different parts of the Carboniferous system scattered pieces and even blocks of granite, gneiss, quartzite, or other durable material which lie imbedded, sometimes singly sometimes in groups, in limestone, sandstone, and in coal. Various explanations have been proposed to account for these erratics, some writers having even suggested the action of drifting ice.[1] The stones were most probably transported by floating plants. Seaweeds, like our living *Fucus*, with their rootlets wrapt round loose blocks might easily be torn up and drifted out to sea, so as to transport and drop their freight among corals and crinoids living on the bottom. But more usually trees growing on the land would envelop soil and stones among their roots, and if blown down and carried away by storms and floods might bear these with them.[2]

Next in abundance to the sandy sediment came the deposits of mud now forming shales. These occur in seams or bands from less than an inch to many yards in thickness. They are commonly black and carbonaceous, frequently largely charged with pyritous impregnations, sometimes crowded with concretions of clay-ironstone. Coal occurs among these strata in seams varying from less than an inch up to several feet or yards in thickness, but swelling out in some rare examples to 100 feet or more. A coal-seam may consist entirely of one kind of coal. Frequently, however, it contains one or more thin layers or "partings" of shale, the nature or quality of the seam being alike or different on the two sides of the parting. The same seam may be a cannel-coal at one part of a mineral field, an ordinary soft coal at a second, and an ironstone at a third. Moreover, in Britain and other countries, each coal-seam is usually underlain by a bed of fire-clay or shale, through which rootlets branch freely in all directions. These fireclays, as their name denotes, are used for pottery or brick-making. They appear to be the soil on which the plants of the coal grew, and it was doubtless the growth of the vegetation that deprived them of their alkalies and iron, and thus made them industrially valuable. In the small coal-basins of Central France the coal is dispersed in banks and isolated veins all through the Carboniferous strata. Clay-ironstone occurs abundantly in some coal-fields, both in the form of concretions (sphærosiderite) and also in distinct layers from less than an inch to eighteen inches or more in thickness. The nodules have generally been formed round some organic object, such as a shell, seed-cone, fern-frond, &c. Many of the ironstone beds likewise abound in organic remains, some of them, like the "mussel-band" ironstone of

[1] For remarks on the climate of the Carboniferous period see *postea*, p. 1019.

[2] For accounts of these travelled stones in Carboniferous rocks see especially D. Stur, *Jahrb. Geol. Reichsanst.* xxxv. (1885), p. 613, and the authorities cited by him. W. S. Gresley, *Geol. Mag.* 1885, p. 553; *Q. J. G. S.* xliii. (1887), p. 734. V. Ball, *op. cit.* xliv. (1888), p. 371.

Scotland, consisting almost wholly of valves of *Anthracosia* or other shell converted into carbonate of iron.

The mode of origin of coal cannot be closely paralleled by any modern formation, and various divergent views have been expressed on the subject. There seem to have been two distinct modes of accumulation: (1) by growth *in situ*, and (2) by drifting from adjacent land. It is possible

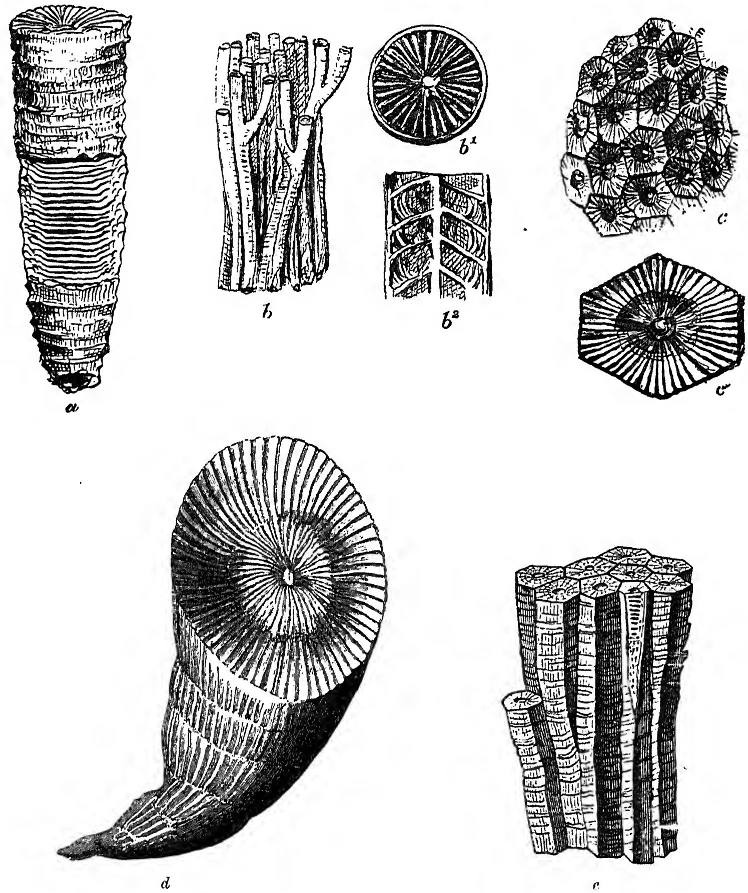


Fig. 390.—Carboniferous Corals.

a, Zaphrentis cylindrica, Scoul.; *b*, Lithostrotion junceum, Flem; *b*1, Do. magnified, transverse section; *b*2, Do. magnified, longitudinal section; *c*, Lithostrotion Portlocki, Milne Edw.; *c*1, Do. calyx magnified; *d*, Cyathophyllum Stutchburyi, Milne Edw.; *e*, Lithostrotion basaltiforme, Phill., sp.

that in some coal-fields both these processes may have been successively or simultaneously in operation, so that the results are commingled.

1. In those cases where the evidence points to growth *in situ*, the coal-seams have been laid down with tolerable uniformity of thickness and character over considerable areas of ground, and they now appear as

regular layers intercalated between sheets of sediment, and for the most part rest on fireclay or shale, into which roots and rootlets may frequently be seen to ramify as in the position of growth.[1] The nearest analogy to these conditions is probably furnished by cypress swamps,[2] and by the mangrove swamps alluded to already (p. 609), where masses of arborescent vegetation, with their roots spreading in salt water among marine organisms, grow out into the sea as a belt or fringe on low shores, and form a matted soil which adds to the breadth of the land. The coal-growths no doubt also flourished in salt water; for such shells as *Aviculopecten* and *Goniatites* are found lying on the coal or in the shales attached to it. Each coal-seam represents the accumulated growth of a period which was limited either by the exhaustion of the soil underneath the vegetation (as may be indicated by the composition of the fire-clays), or by the rate of the intermittent subsidence that affected the whole area of coal-growths. Though the vegetation in these coal-fields may have grown as a whole *in situ*, there may also have been considerable transport of loose leaves, branches, trunks, &c., after storms, and also during times of more rapid subsidence. From the fact that a succession of coal-seams, supposing each to represent a former surface of terrestrial vegetation, can be seen in a single coal-field to extend through a vertical thickness of 10,000 feet or more, it is clear that the strata of such a field must have been laid down during prolonged and extensive subsidence. It has been assumed that, besides depression, movements in an upward direction were needful to bring the submerged surfaces once more up within the limits of plant growth. But this would involve a prolonged and almost inconceivable sea-saw oscillation; and the assumption is really unnecessary if we suppose that the downward movement, though prolonged, was not continuous, but was marked by pauses, long enough for the silting-up of lagoons and the spread of coal-jungles.[3]

That the vegetation actually grew on the spot where its remains are now found is further shown by the succession of platforms of vertical tree-trunks standing in their positions of growth and with their roots branching freely in the sediment on which they had sprung up. In these instances there may be no coal-seam, as, on the other hand, there are vast numbers of coal-seams without the accompaniment of vertical stems. The St. Etienne coal-field displays a succession of these forests, and in that of Nova Scotia Dawson enumerated no fewer than sixty-eight, one above another. Grand' Eury has shown that it was not merely one genus

[1] For arguments in support of the view that coal was formed of plants *in situ* see Logan, *Trans. Geol. Soc.* vi. (1842), p. 491. Newberry, *Amer. Journ. Sci.* xxiii. (1857), p. 212; 'Geol. Surv. Ohio,' vol. ii. Geology, p. 125; *School of Mines Quarterly*, New York, April 1893. Gümbel, *Sitzb. Bayer. Akad.* 1883. W. S. Gresley, *Geol. Mag.* 1901, p. 29. C. E. Bertrand and B. Renault, *Compt. rend.* cxvii. (1893), p. 539, where evidence is given of the formation of "boghead" from algæ. The origin of coal formed the subject of a discussion at the British Association in 1900, *Report*, p. 746.

[2] For an account of the submerged lands (Dismal Swamp) of the Mississippi, see Lyell's Second Visit to the United States,' chap. xxxiii.

[3] See a statement of the oscillation theory as far back as 1849 by M. Virlet d'Aoust, *B. S. G. F.* (2) vi. p. 616.

or group of trees that had this aquatic habitat, but that all the more important arborescent plants actually lived in swamps or shallow water with their roots in the sand or mud of the bottom,—*Stigmaria*, *Syringodendron*, *Stigmariopsis*, *Sigillaria*, *Calamites*, *Calamodendron*, tree-ferns (*Psaronius*, *Aulacopteris*, &c.), and *Cordaites*.[1]

2. Those who advocate the view that most coal-seams have resulted from the deposit of transported vegetation point to the evident stratification of the coal and to the intercalation of thin seams or laminæ of shale in the seams. Coal passes laterally into shale and ironstone, sometimes even into dolomite.[2] Moreover, the researches of Grand' Eury, Fayol, and others in the small coal-basins of Central France have shown that in these regions much vegetable matter was washed down from adjacent land.[3] The coal is irregularly distributed among the strata, and it is associated with beds of coarse detritus and other evidence of torrential action. Numerous trunks of calamododendra, sigillariæ, and other trees imbedded in the sandstones and shales vertically and at all angles of inclination bear witness, like the "snags" of the Mississippi, to the currents that transported them. The basins in which the accumulated detritus and vegetation were entombed seem to have been small, but sometimes comparatively deep, lakes lying on the ancient crystalline rocks that formed an uneven land-surface during the Carboniferous period in the heart of France. But there is evidence, even in these basins, of the growth of coal-plants *in situ*, and of the gradual subsidence of the alluvial floors on which they took root. Grand' Eury, in studying the tree-trunks with their roots in place on many successive levels in the coal fields of Central France, has ascertained that these trees, as they were enveloped in sediment, pushed out rootlets at higher levels into the silt that gathered round them.

It would thus appear that no one hypothesis is universally applicable for the explanation of the origin of coal, but that growth on the spot and transport from neighbouring land have both in different regions contemporaneously and at successive periods come into play.

In this place reference may most conveniently be made to the probable climate in which these geological changes took place. The remarkable profusion of the vegetation of the Carboniferous period, not only in the Old World but in the New, suggested the idea that the atmosphere was then much more charged with carbonic acid than it now is. Undoubtedly there has been a continual abstraction of this gas from the atmosphere ever since land-plants began to live on the earth's surface, and it is

[1] See his series of papers in the *Compt. rend.* for 14th June 1897 and April to July 1900; *Compt. rend. Congrès Géol. Internat*, Paris, 1900, p. 520.

[2] A. Strahan, *Q. J. G. S.* lvii. (1901), p. 297.

[3] For the detrital origin of coal, see Grand' Eury, *Ann. des Mines*, 1882 (i.), pp. 99-292; *Mem. S. G. F*, 3e sér. iv. 1887; 'Géol. et Paléontol. du bassin Houiller du Gard,' 1891; *Compt. rend.* cxxiv. (1897), cxxx. (1900). Fayol, 'Études sur le Terrain Houiller de Commentry,' Part 1; *Bull. Soc. Industrie Min.* sér. 2, vol. xv. and Atlas (1887); *B. S. G. F.* 3e sér. xvii. (1888). B. Renault, 'Flore Fossile de Commentry,' *Bull. Soc. Hist. Nat. d'Autun* (1891). A. de Lapparent, *Rev. Quest. Scien.* July 1892.

allowable to infer that the proportion of it in the air in Palæozoic time may have been somewhat greater than now. But the difference could hardly have been serious, otherwise it seems incredible that the numerous insects, labyrinthodonts, and other air-breathers, could have existed. Most probably the luxuriance of the flora is rather to be ascribed to the warm moist climate which in Carboniferous times appears to have spread over the globe even into Arctic latitudes. On the other hand, evidence has been adduced to support the view that in spite of the genial temperature indicated by the vegetation there were glaciers even in tropical and sub-tropical regions. Coarse boulder-conglomerates and striated stones have been cited from various parts of India, South Africa, and Eastern Australia, as evidence of ice-action. These will be more particularly noticed farther on.

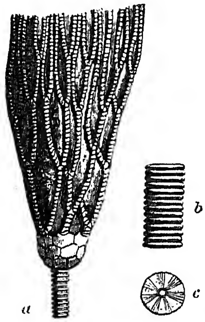


Fig. 391.—Carboniferous Crinoid.

Cyathocrinus planus, Miller; *a*, calyx, arms and upper part of stem; *b*, portions of the stem; *c*, one of the column-joints showing central canal.

LIFE.—Each of the two facies of sedimentation above described has its own characteristic organic types, the one series of strata presenting us chiefly with the fauna of the sea, the other mainly with the flora of the land.

I. The MARINE fauna is specially rich in crinoids, corals, and brachiopods, which of themselves constitute entire beds of limestone. Among the lower forms of life the Foraminifera are well represented. The genera include *Saccammina*, *Endothyra*, *Valvulina*, *Climacammina*, *Stacheia*, *Lagena*, *Nodosaria*, *Textularia*, *Archædiscus*, *Fusulina*. Some of these genera exhibit a wide geographical range; *Saccammina*, for example, forms beds of limestone in Britain and Belgium; *Fusulina* plays a still more important part in the Carboniferous Limestone of the region from Russia to China and Japan, as well as in North America; while a species of *Valvulina* (*V. palæotrochus*) extends from Ireland to Russia on the one side and to North America on the other. As already noticed, species of organisms, with a wide geographical extension, have also a long geological range, and this is more specially exemplified in such lowly grades of existence as the foraminifera. The form named *Trochammina incerta*, for instance, is found through the whole Carboniferous Limestone series of England, reappears in the Magnesian Limestone of the Permian system, and occurs not only in Britain but in Germany and Russia, while *Saccammina* is a still living genus.[1] Radiolaria are extremely abundant on some horizons in the Lower Carboniferous formations, where they form layers of dark chert and occur also in soft grey shales. Thus the Lower Culm of Devon and Cornwall has yielded twenty-three genera, seventeen of which are common to the Culm of Germany, Sicily, and Russia.[2] The existence of Sponges in the Carbon-

[1] H. B. Brady, 'Monograph of Carboniferous and Permian Foraminifera,' *Palæontog. Soc.* (1876).

[2] G. J. Hinde and H. Fox, *Q. J. G. S.* li. (1895), pp. 609-668.

iferous seas is shown by the occurrence of siliceous spicules, more rarely by entire specimens,[1] and by early types of the calcareous pharetrones and sycones. Corals (Fig. 390) are represented by tabulate (*Michelinia, Aulopora, Chladochonus, Chætetes*, especially prominent as a reef builder,

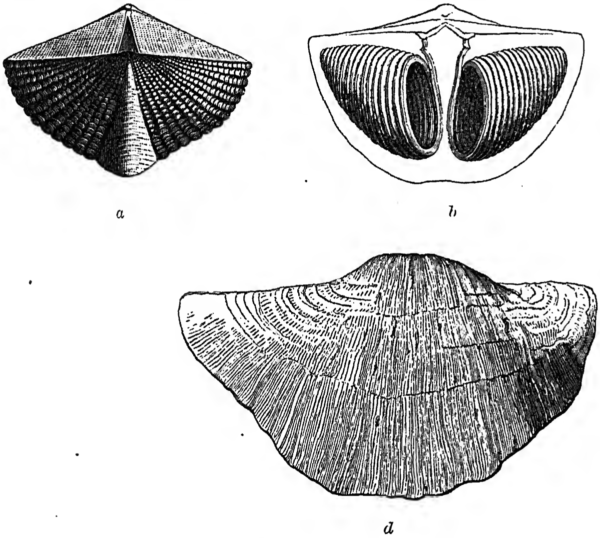


Fig. 392.—Carboniferous Brachiopods.
a, Spiriferina laminosa, M'Coy; *b*, Spirifer striatus, interior of dorsal valve, showing spiral calcareous supports for the arms; *c*, Terebratula (Dielasma) hastata, Sow.; *d*, Productus giganteus, Martin (½).

and the ancient and waning genus *Favosites*), and still more by rugose forms (*Amplexus, Zaphrentis, Cyathophyllum, Aulophyllum, Clisiophyllum, Lithostrotion, Lonsdaleia, Phillipsastræa*). Among the Echinoderms, which

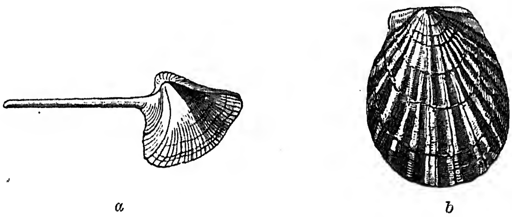
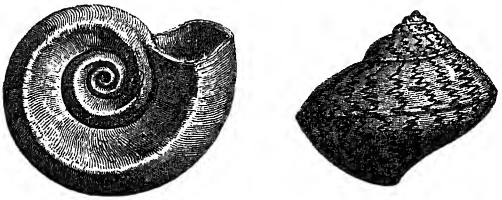


Fig. 393.—Carboniferous Lamellibranchs.
a, Conocardium aliforme, Sow.; *b*, Aviculopecten (Streblopteria?) sublobatus, Phill., showing colour-bands.

were abundant and varied, the sea-urchins were represented by *Archæocidaris, Perischodomus* (*Koninckocidaris*), *Lepidocidaris, Palæchinus*, and *Melonechinus* (*Melonites*). The blastoids, which now took the place in

[1] As in the *Pemmatites* from Yorkshire, described by Dr. Hinde, *Q. J. G. S.* lii. (1896), p. 438.

Carboniferous waters that in Silurian times had been filled by the cystideans, attained their maximum development, nineteen genera and upwards of 120 species having been found in the sub-Carboniferous group of North America (*Pentremites*, *Codaster*, *Orbitremites*, &c.). But it was the order of crinoids that chiefly swarmed in the seas where the Carboniferous Limestone was laid down, their separated joints now mainly composing solid masses of rock several hundred feet in thickness. Among their most conspicuous genera were *Platycrinus*, *Eucladocrinus*, *Dichocrinus*, *Actinocrinus*, *Batocrinus*, *Rhodocrinus*, *Belemnocrinus*, *Cyathocrinus*, (Fig. 391), *Poteriocrinus*, *Woodocrinus*, and *Taxocrinus*. Tubicolar Annelids



a b

Fig. 394.—Carboniferous Gasteropods.
a, Euomphalus pentangulatus, Sow.; *b*, Pleurotomaria carinata, Sow., showing colour-bands.

abounded, some of the species being solitary and attached to shells, corals, &c., others occurring in small clusters and some in gregarious masses forming beds of limestone (*Spirorbis*, *Serpulites*, *Ortonia*). Free-swimming forms are represented by detached jaws and toothed plates,[1] and by abundant burrows and trails among the sedimentary strata. Bryozoa abound in some portions of the Carboniferous Limestone, which were almost entirely composed of them, the genera *Fenestella*, *Rhombopora*, *Polypora*, *Archimedes*, *Thamniscus*, and *Pinnatopora* (*Glauconome*) being frequent.

Of the Brachiopods (Fig. 392) some of the most common forms are *Productus* (a characteristic genus), *Spirifer*, *Rhynchonella* (*Pugnax*, *Hypothyris*, &c.), *Athyris*, *Chonetes*, *Orthis*, *Terebratula* (*Dielasma*), *Leptæna*, *Derbya*, *Lyttonia*, *Lingula*, *Orbiculoidea* (*Discina*), and *Crania*.[2] There are species that appear to range over the whole world, such as *Productus semireticulatus*, *costatus*, *longispinus*, *pustulosus*, *cora*, *aculeatus*, *undatus*; *Orthothetes* (*Streptorhynchus*) *crenistria*; *Spirifer lineatus*, *glaber*; *Athyris globularis*; and *Terebratula* (*Dielasma*) *hastata*. Mollusks now begin to preponderate over brachiopods. The Lamellibranchs (Fig. 393) include forms of *Aviculopecten*, *Posidonomya*, *Nuculana* (*Leda*), *Nucula*,

[1] G. J. Hinde, *Q. J. G. S.* xxxv. p. 370, 386; xxxvi. pp. 368; lii. p. 448.

[2] *Productus* is almost wholly Carboniferous, and in the species *P. giganteus* (Fig. 392, *d*) of the Carboniferous Limestone reached the maximum size attained by the brachiopods, some individuals measuring nearly twelve inches across. Other genera had already existed a long time; some even of the species were of ancient date—*Orthis resupinata* of the Carboniferous Limestone and the Devonian *O. striatula* and *Strophomena depressa* had survived, according to Gosselet, from the time of the Bala beds of the Lower Silurian period (Gosselet, *Esquisse*, p. 118).

Sanguinolites, *Schizodus*, *Edmondia*, *Carbonicola* (*Anthracosia*), *Anthracomya*, *Naiadites*, *Myalina*, *Modiola*, and *Conocardium*. The Gasteropods (Fig. 394) are represented by numerous genera, among which *Euomphalus*, *Naticopsis*, *Murchisonia*, *Pleurotomaria*, *Macrochilina* and *Loxonema* are frequent. The genus *Bellerophon* is represented by many species, among which *B. Urei* and *B. decussatus* are specially common. Another abundant genus is *Conularia* (Fig. 395), which often attains a length of several inches. Of the Cephalopods (Fig. 396) the most abundant and widely distributed are forms of *Orthoceras*, *Cyrtoceras*, *Actinoceras*, *Poterioceras*, *Discites*, *Cœlonautilus*, *Glyphioceras* (*Goniatites*), *Gastrioceras* and *Prolecanites*.

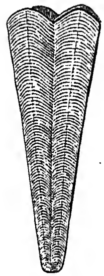


Fig. 395. Conularia quadrisulcata, Sow. Carboniferous Limestones.

The Crustacea present a facies very distinct from that of the previous Palæozoic formations. Trilobites now almost wholly disappear, only five genera of small forms of the single family of the Proëtidæ (*Proëtus*, *Griffithides*, *Phillipsia*, *Brachymetopus*) being left. But other crustacea are abundant, especially ostracods (*Bairdia*, *Cypridellina*, *Cythere*, *Kirkbya*, *Leperditia*,

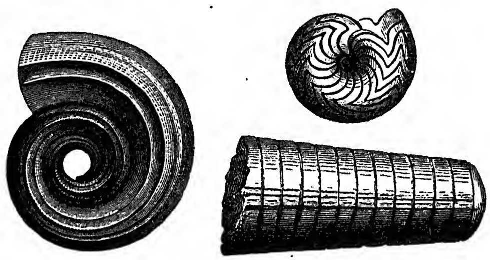


Fig. 396.—Carboniferous Cephalopods.
a, Nautilus (Discites) Koninckii, D'Orb.; *b*, Goniatites crenistria, Phill.; *c*, Orthoceras (Breynii, Mart.; laterale, Phill.).

Beyrichia, &c.), which crowd many of the shales and sometimes even

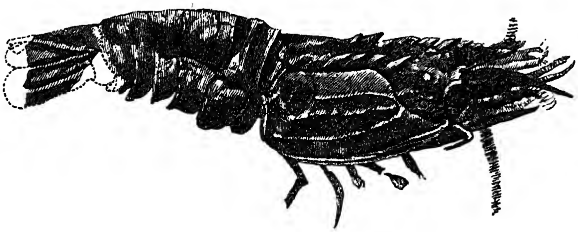


Fig. 397.—Carboniferous Schizopod.
Anthrapalæmon Etheridgii, Peach, twice nat. size.

form seams of limestone. Some schizopod forms are met with (*Palæocaris*, *Pseudogalathea*), and a few occur not infrequently, particu-

larly *Anthrapalaemon* (Fig. 397) and *Palaeocrangon* (*Crangopsis*).[1] Several phyllocarids (*Dithyrocaris*, *Ceratiocaris*) appear, together with some phyllopods (*Estheria*, *Leaia*), and with the larger merostomatous

Fig. 398.—Carboniferous Ichthyodorulite, or Dorsal Fish-spine.
Sphenacanthus hybodoides, Egerton.

Eurypterus and king-crabs (*Prestwichia*, *Belinurus*). The Carboniferous Limestone of the British Isles has supplied more than 100 genera of fishes, chiefly represented by teeth and spines (*Psammodus*, *Cochliodus*,

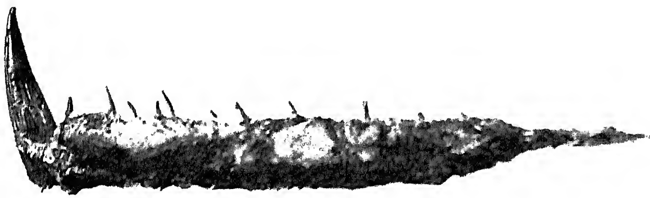


Fig. 399.—Carboniferous Fish.
Jaw of Rhizodus Hibberti, Ag. sp., one-third nat. size.

Cladodus, *Petalodus*, *Ctenodus*, *Rhizodus*, *Ctenoptychius*, &c.). Some of these were no doubt selachians which lived solely or usually in the sea, but many, if not all, of the ganoids probably migrated between salt and fresh water; at least their remains are found in Scotland not only in

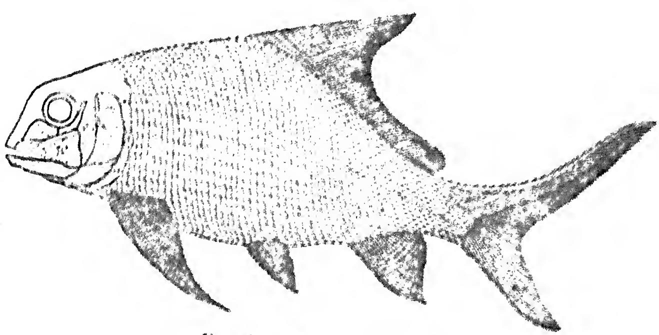


Fig. 400.—Carboniferous Fish.
Eurynotus crenatus, Ag., "Cement-stones" of Scotland (after Traquair).

marine limestones, but also in strata full of land plants, cyprids, and other indications of estuarine or fluviatile conditions. Some of the fishes met

[1] The supposed Carboniferous Macrura are now regarded as Schizopods; see B. N. Peach, *Proc. Roy. Phys. Soc. Edin.* xiv. (1901), p. 370.

with in the plant-bearing type of the Carboniferous system are mentioned on p. 1031, together with the air-breathers and other terrestrial organisms. The Carboniferous system of the United States has likewise furnished a large list of fossil fishes. The census given in 1889 by Newberry comprised nearly 400 species from the Carboniferous Limestone series. They were nearly all elasmobranchs, recognisable as a rule only by teeth and spines or dermal tubercules. The Coal-measures of America have also yielded, as in Europe, a great many ichthyolites, chiefly small tile-scaled ganoids allied to *Palæoniscus*, but a considerable number of larger forms of the same order (*Rhizodus*, *Megalichthys*, *Cœlacanthus*), together with dipnoans (*Ctenodus*) and numerous elasmobranchs represented by teeth (*Cladodus*, *Diplodus*, *Petalodus*) or by spines (*Edestus*, *Ctenacanthus*, *Orthacanthus*).[1]

It is deserving of remark that in the marine type of the Carboniferous system considerable differences may be observed between the distribution of the fossils in the limestones and shales even of the same quarry. The limestones, for example, may be crowded with the joints of crinoids, corals of various kinds, producti and other brachiopods, while the shales above them may contain few of these organisms, but afford polyzoa, *Conularia*, horny brachiopods (*Lingula*, *Orbiculoidea*), many lamellibranchs, especially pectens, aviculopectens, nuculas, ledas, and gasteropods (*Pleurotomaria*, *Loxonema*, *Bellerophon*, &c.). It is evident that while some organisms flourished only in clear water, such as that in which the limestones accumulated, others abounded on a muddy bottom, although some seem to have lived in either situation, if we may judge from finding their remains indifferently in the calcareous and the muddy deposits.

II. The LAGOON phase of sedimentation, or that of the coal-swamps, is marked by a very characteristic suite of organic remains. Most abundant of these are the plants, which possess a special interest, inasmuch as they form the oldest terrestrial flora that has been copiously preserved.[2] This flora presents a singular monotony of character all over the northern hemisphere, from the Equator into the Arctic Circle, the same genera, and sometimes even the same species, appearing to have ranged over the whole surface of the globe. It consisted almost entirely of vascular cryptogams, and pre-eminently of Ferns, Equisetaceæ, and Lycopodiaceæ, but with some gymnosperms allied to cycads and yews. The presence of Algæ in the coal-swamps has now been proved by the

[1] J. S. Newberry, *Monograph* xvi. (1889), *U.S. G. S.*

[2] On the Carboniferous flora, consult A. Brongniart, 'Prodrome d'une Histoire des Végétaux fossiles,' 1828. Lindley and Hutton, 'Fossil Flora of Great Britain,' 1831-37. C. E. Weiss, 'Fossile Flora d. jüngsten Steinkohl im Saar-Rhein-Geb,' Bonn, 1869-72; 'Die Flora d. Steinkohlen Formation,' Berlin, 1881. Williamson's Memoirs "On the Organisation of the Plants of the Coal-measures," *Phil. Trans.* clxii. (1872), and subsequent volumes. Zeiller, on the Carboniferous flora of Valenciennes, Autun, and Brive, in the series of volumes entitled 'Etudes des Gites Minéraux de la France,' published by the Ministry of Public Works. D. Stur, "Die Culm-flora," *Abhand. K.K. Geol. Reichsanst*, Vienna, viii. (1875). Zeiller and Renault on Fossil Flora of Commentry, *Bull. Soc. Indust. Min. St. Étienne*, 2 vols. with Atlas, 1888-90. R. Kidston, *Trans. R. S. Edin.* xxx. xxxv. xxxvii. D. White, "Fossil Flora of Lower Coal-measures of Missouri," *Monog. U.S. G. S.* No. xxxvii. 1899.

detection of their remains among the sediments, and as main constituents of some of the varieties of cannel-coal (boghead). Fungi have also been detected on the leaves of ferns, *Cordaites* and other plants. Although the plants of the Carboniferous system are referable, in many cases, to still living types of vegetation, they presented many remarkable differences from these. In particular, save in the case of the ferns, they much exceeded in size any forms of the present vegetable world to which they can be assimilated. Our modern horse-tails had their allies in huge trees among the Carboniferous jungles, and the familiar club-moss of our hills, now a low creeping plant, was represented by tall-stemmed *Lepidodendra* that rose fifty feet or more into the air. The ferns, however, present no such contrast to forms still living. On the contrary, they often recall modern genera, which they resemble not merely in general aspect, but even in their circinate vernation and fructification. With the exception of a few tree-ferns, they seem to have been low-growing plants, and perhaps were to some extent epiphytic upon the larger vegetation of the lagoons. Some of the more common genera are *Rhacopteris*, *Calymmatotheca* (Fig. 401), *Sphenopteris* (upwards of two dozen of species), *Neuropteris* (a dozen or more species, Fig. 402 *a*), *Cyclopteris*, *Odontopteris*, *Mariopteris*, *Pecopteris* (many species), *Alethopteris* (Fig. 402 *b*).[1] There occur also the stems of tree-ferns (*Megaphyton*, *Caulopteris*).

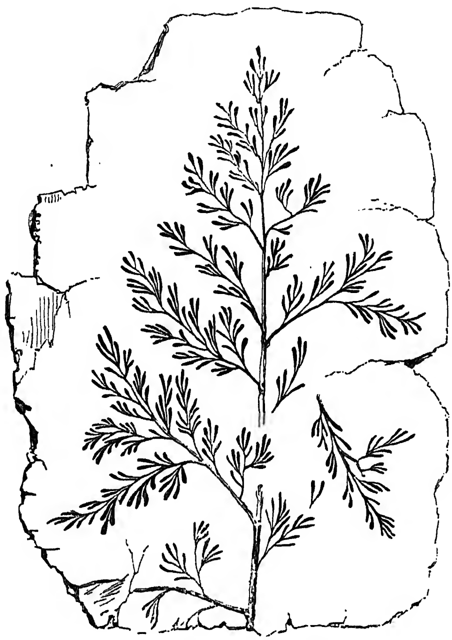


Fig. 401.—Carboniferous Fern.
Calymmatotheca (Sphenopteris) affinis, Lindl. and Hutt.

Among the Equisetaceæ,[2] the genus *Calamites* is specially abundant. It usually occurs in fragments of jointed and finely-ribbed stems. From the joints or nodes of the stem numerous branches were given off, and numerous rootlets proceeded, whereby the plants were anchored in the mud or sand of the lagoons, where they grew in dense thickets. According to Dawson they seem to have fringed the great jungles of Sigillariæ, and to have acted as a filter that cleared the water of its sediment and prevented the vegetable accumulations of the coal-swamps from admixture with muddy sediment. To the foliage of Calamites

[1] For an essay on the morphology and classification of the Carboniferous ferns see D. Stur, *Sitzb. Akad. Wien.* lxxxvi. (1883).

[2] On Carboniferous Calamaries, consult Weiss, *Abh. Geol. Specialkarte Preussen*, v.

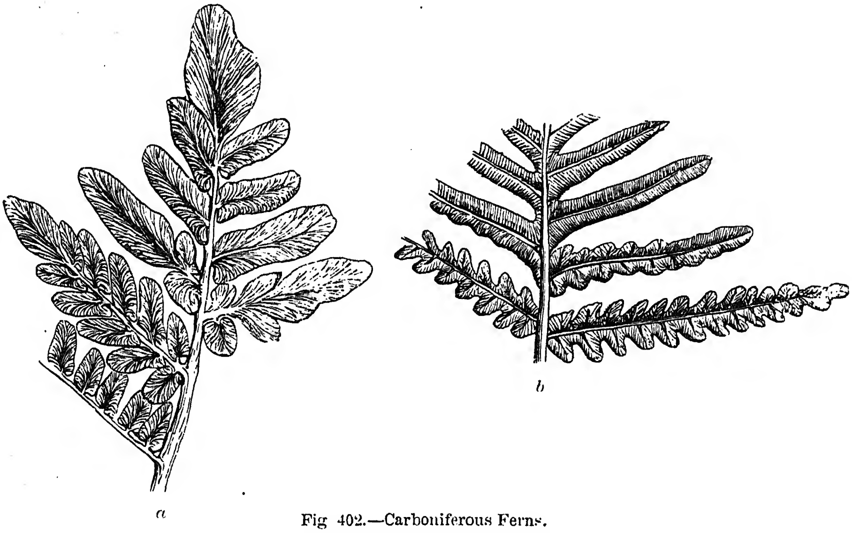


Fig 402.—Carboniferous Ferns.
a, Neuropteris heterophylla, Brongn. ; *b*, Alethopteris Gibsoni Lesq.

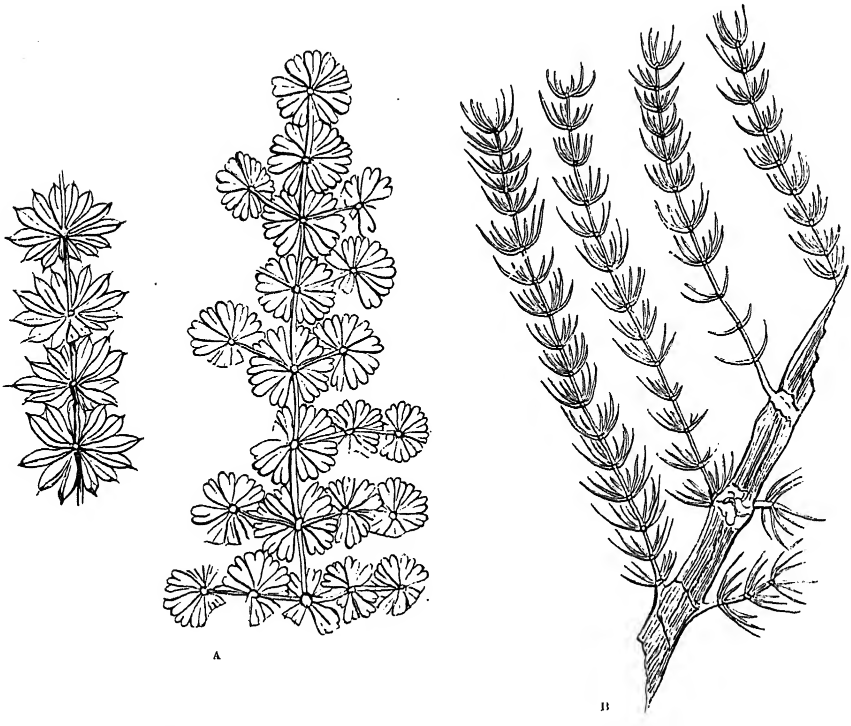


Fig. 403.—A, Annularia sphenophylloides, Zenker; B, Asterophyllites.

different generic appellations have been attached (Fig. 403). *Calamocladus* (*Asterophyllites*) is given to jointed and fluted verticils of slim branches proceeding from the joints and bearing of long, narrow, pointed leaves. *Annularia* has the close united at the base. *Calamodendron* is believed by some botanists the cast of the pith of a woody stem belonging to some unknown others it is regarded as only a condition of the preservation of Some examples of the fructification of the calamites have been Of these *Pothocites* has been found attached to *Asterocalamites*; *annularia* is probably the cone of *Annularia*, while others, *Volkmannia*, *Calamostachys* and *Macrostachya*, are probably the fr of calamites. *Sphenophyllum* is the name given to a genus of which the leaves are borne in whorls of six, or some multi and are wedge-shaped.

The Lycopods (Fig. 404) were distinguished by the leaf-sc dichotomous stems. Their branches, closely covered with poi bore at their ends cones or spikes (*Lepidostrobus*) consisting of axis, round which were placed imbricated scales, each carrying a Of the type genus *Lepidodendron* there are many species; ot are *Lepidophloios*, *Halonia*, *Omphalophloios* and *Bothrodendron*.

Among the most remarkable trees of the Carboniferous f the Sigillarias, which are believed to have been akin to t dendra. The genus *Sigillaria* was distinguished by the great feet or more) of its trunk, which sometimes measured five feet i Its stem was fluted (Fig. 405), and marked by parallel p lines of leaf-scars. The base of the stem passes into the root *Stigmaria*, the pitted and tuberculed stems of which are su fossils (Figs. 405 B, and 406). There can be little doubt, ho *Stigmaria* was a form of root common to more than one ki The genus *Cordaites* belonged to a type of tree which had af to the cycads and to the conifers, but was very different from attained a great profusion in the time of the Coal-measures. S to a height of 20 or 30 feet, it carried narrow or broad, par leaves, somewhat like those of a Yucca, which were attached t by broad bases at rather wide distances, and on their fall left leaf-scars. It bore catkins which ripened into berries not unli yews (*Cardiocarpus*) (Fig. 408). Both of these forms of fr occur in great abundance in some bands of shale. Other f certain parentage are named, *Rhabdocarpus*, *Carpolithus*, and *T* The latter has been supposed to belong to some mem Cordaitaceæ, somewhat like the fruit of the living *Ginkgo* (*Sali*

Large stems having a well-preserved internal structure preserved in the sandstones, where they occur as drift-wood from higher ground (Fig. 407). Some of these ancient trees 50 to 70 feet in length. They have been grouped under t names *Calamopitys*, *Pitys*, and *Dadoxylon*, and their pith-casts been known as *Sternbergia* or *Artesia*. Recent research has sh these stems belong to the Cordaitaceæ, and that while their st

in many respects, similar to that of gymnosperms, they also possess some

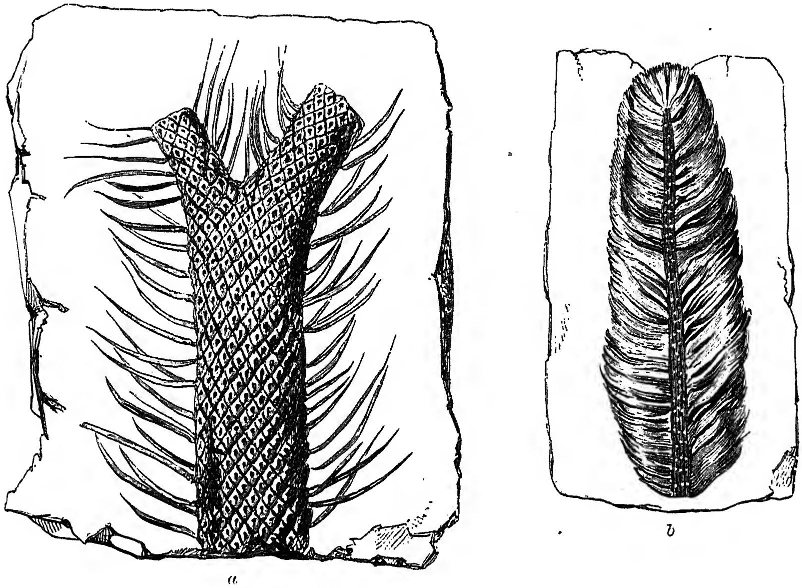


Fig. 404.—Carboniferous Lycopods.
a, Lepidodendron (¼); *b*, Lepidostrobus, nat. size.

of the characters of the Cycadoficales.[1] There would appear to have been

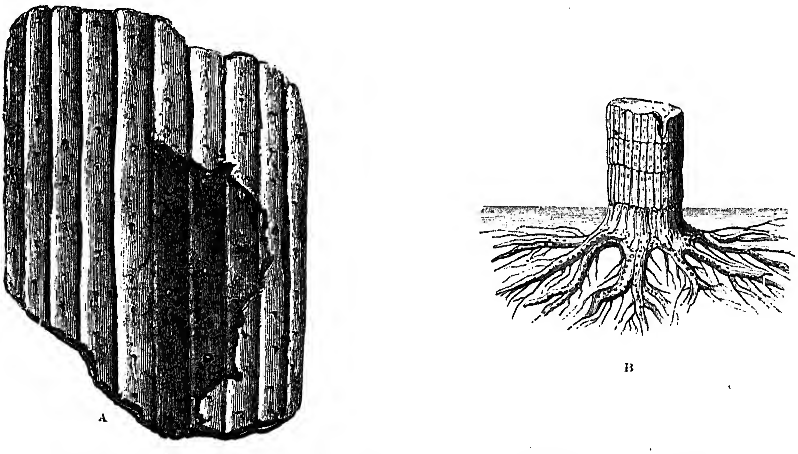


Fig. 405.—A, Sigillaria; portion of decorticated stem; B, Sigillaria stem terminating in Stigmarian Roots and Rootlets.

also coniferous trees in the Carboniferous flora. *Walchia*, a characteristic-

[1] D. H. Scott, *Trans. Roy. Soc. Edin.* xl. (1902) p. 331.

ally Permian conifer, appears at the top of the Coal-measures. That true monocotyledons existed in the Carboniferous period was formerly

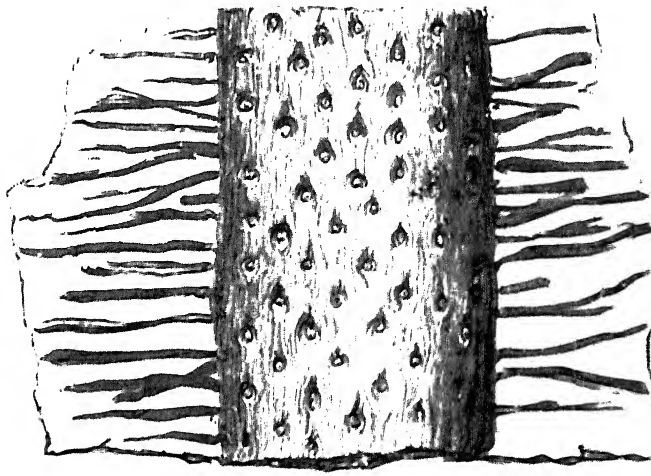


Fig. 406.—Stigmaria with attached rootlets.

supposed to be proved by the discovery of a number of spikes, referred to the living order of Aroideæ (*Pothocites*), in the lower part of the Carboniferous system of Scotland, until Mr. R. Kidston showed that

Fig. 407.—Tree-trunk (*Pitys Withami*, Lindl. Hutt.) imbedded in Sandstone, Craigleith, Edinburgh (after Witham).

the specimens are the fructification of *Asterocalamites scrobiculatus*, a genus of Calamite.[1]

[1] *Ann. Mag. Nat. Hist.* May 1883, p. 297.

The animal remains in the coal-bearing part of the Carboniferous rocks are comparatively few. As already stated, certain bands of shale, coal, and ironstone in the lower half of the Coal-measures afford undoubted proofs of the presence of the sea by the occurrence of some of the familiar shells of the Carboniferous Limestone. But towards the upper part of the Coal-measures, where these marine forms almost entirely disappear (among their last representatives being species of *Lingula* and *Orbiculoidea*), other mollusks, that were probably denizens of brackish if not of fresh water, occur in abundance. Among the more frequent are *Anthracomya*, *Carbonicola* (*Anthracosia*), and *Naiadites* (*Anthracoptera*).[1] Arthropods are represented by vast numbers of ostracods (*Bairdia*, *Beyrichia*, *Bythocypris*, *Carbonia*, *Cytherella*, *Leperditia*); by a few phyllopods (*Estheria*, *Leaia*); phyllocarids (*Dithyrocaris*, *Acanthocaris*); schizopod crustaceans (*Anthrapalaemon*, Fig. 397); and eurypterids (*Eurypterus*, *Glyptoscorpius*). Fishes

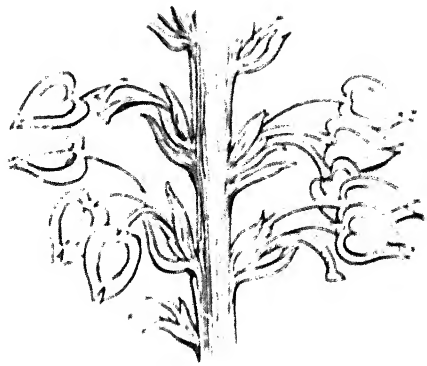
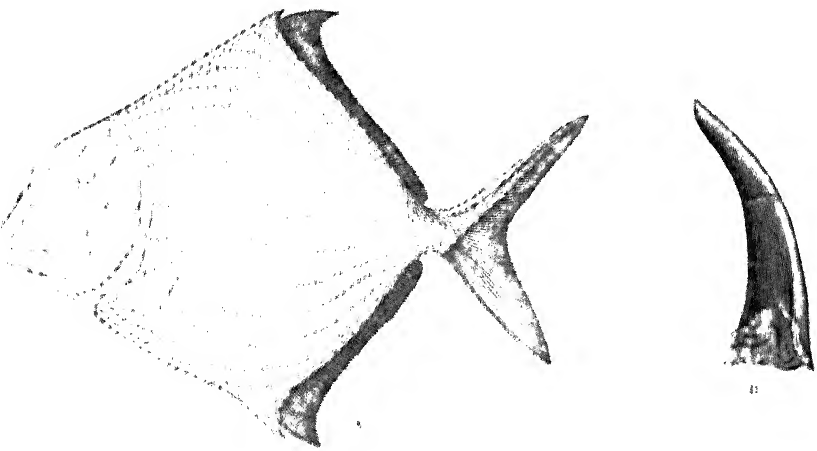


Fig. 39[illegible].—Inflorescence with Cardiocarpus.



[illegible] Fishes.

[illegible] Strepsodus sauroides, Binney, sp.

are found frequently, remains of the larger kinds usually appearing in scales, teeth, fin-spines, or bones, while the smaller ganoids are often preserved entire. Common genera are *Ctenodus*, *Uronemus*, *Acanthodes*, *Rhizodus*, *Strepsodus* (Fig. 398, b), *Megalichthys*, *Elonichthys*, *Rhadinichthys*,

[1] Dr. Wheelton Hind, [illegible] Naiadites, Palaeontograph. Soc.

Nematoptychius, *Gonatodus*, *Eurynotus*, *Cheirodus* (Fig. 409, A), *Ctenacanthus*, *Gyracanthus*, *Pleuracanthus*, and *Ctenoptychius*.

The presence of true air-breathers among the jungles of the Carboniferous period has been established by the discovery of numerous specimens of arachnids, insects, myriapods, pulmonate mollusks, and labyrinthodonts. According to the census of Mr. Scudder there were known up to 1890 no fewer than 75 species of Carboniferous arachnids.[1] Scorpions (*Eoscorpius*) have been found both in Europe and America, and have been obtained in great numbers, in excellent preservation and of gigantic size, in the Lower Carboniferous rocks of Scotland (Fig. 410). Other arachnids occur, including ancient forms of spider (*Protolycosa*). Myriapods, of which upwards of 40 species have been determined, were represented by various plant-eating millipedes (*Xylobius*, *Archiulus*, *Euphoberia*). True insects likewise flitted through these dense jungles. Mr. Scudder's census of 1891 contained 239 species of orthoptera, 109 of neuroptera, 17 of hemiptera and 11 assigned to coleoptera. M. Charles Brongniart, in his great Monograph published in 1894, enumerated as having been found in the Carboniferous rocks, principally in the Commentry Coal-field of Central France, upwards of 40 genera of neuroptera, and 19 of orthoptera. But these numbers are continually on the increase. Thus the number of known Palæozoic genera of cockroaches, the predominant insects, in the year 1879 was 58, and in 1893 amounted to 193.[2] The Carboniferous insects included ancient primitive forms of cockroach, cricket, and beetle. It is remarkable that from some coal-fields hardly a single trace of insect life has been obtained, while in others great numbers of specimens have been brought to light. A variety of forms has been found in the Saarbrück Coal-field; but perhaps the greatest number of individual specimens has come from that of Commentry, which up to the end of the year 1884 was computed to have furnished not less than 1300 individuals. Some of the insects were of considerable size. Thus the orthopterous *Archæoptilus* from the Derbyshire Coal-field had a spread of wing of perhaps fourteen inches or more; and a species of *Dictyoneura* (*D. Monyi*) had a wing about 12 inches in length. Others were remarkable for the vividness of their colouring (*Brodia*), the markings of which are still recognisable in the fossil specimens. One of the most singular features yet observed among these ancient insects is the union in the same individual of types of structure which are now entirely distinct.

Fig. 410.—Carboniferous Scorpion. Eoscorpius glaber (B. N. Peach), Lower Carboniferous, Eskdale, Scotland.

[1] *B. U.S. G. S.* No. 71 (1891). The number has since been increased. See the later synopses of Dawson and Brongniart quoted below.

[2] Scudder, *B. U.S. G. S.* No. 124 (1895), p. 21.

M. Ch. Brongniart has shown that wings which were admittedly neuropterous, and were referred to the genus *Dictyoneura*, were really attached to bodies which are unquestionably orthopterous.[1]

An interesting discovery was made by Lyell and Dawson in 1850 when they found that the erect fossil trees in the coast-section of Carboniferous strata, South Joggins, Nova Scotia, decayed in the centre while still standing, and have consequently preserved in their interior remains of some of the air-breathers of the time. Since that time the progress of research has brought to light a large number of specimens which, at the last census published by Dawson in 1894, included 26 species of vertebrates, 33 of arthropoda (insects, scorpions, and myriapods), and 5 of pulmonate mollusks. The insects comprise species of cockroach (*Archimylacris*, *Mylacris*, *Petrablattina*), mayfly (*Platephemera*), and stick-insects (*Haplophlebium*). The vertebrates are all small amphibians, which probably crawled into the hollow tree-trunks to die. The pulmonate shells were land-snails (*Dendropupa*, *Pyramidula*, *Archæozonites*).[2]

The earliest known amphibia appeared in Carboniferous times, and, so far as known, all belonged to the order Stegocephalia (Labyrinthodonts, &c.).[3] They had a salamander-like body with relatively weak limbs and a long tail. Sometimes the limbs seem to have been undeveloped, so that the body was serpent-like. The head was protected by bony plates, and there was likewise a ventral armour of integumentary scales. The British Carboniferous rocks have yielded about 20 genera (*Anthracosaurus*, *Loxomma*, *Ophiderpeton*, *Pholiderpeton*, *Pteroplax*, *Keraterpeton*, *Urocordylus*, &c.). These were probably fluviatile animals of predaceous habits, living on fish, crustacea, and other organisms of the fresh or salt waters of the coal-lagoons. The tree trunks of Nova Scotia above alluded to have furnished 9 genera of small, no doubt terrestrial, forms (*Hylonomus*, *Hylerpeton*, *Dendrerpeton*). The larger amphibia of the time are believed to have measured 7 or 8 feet in length; some of the smaller examples, though adult and perfect, do not exceed as many inches.[4] The coal-field of Bohemia, which may be in

[1] Ch. Brongniart, *B. S. G. F.* (3), xi. p. 142; 'Recherches pour servir à l'histoire des Insectes Fossiles des Temps Primaires,' 2 vols. quarto, St. Étienne, 1894. Scudder, *Geol. Mag.* 1881, p. 293, 1896, p. 10; *Mem. Boston. Soc. Nat. Hist.* iii. (1883), p. 213; *Proc. Amer. Acad.* 1884, p. 167; *B. U. S. G. S.* Nos. 31, 69, and 124. H. Woodward, *Q. J. G. S.* 1872, p. 60. J. W. Dawson's "Synopsis," cited in the following note. The student interested in the study of fossil insects will find Mr. Scudder's Bibliography of the subject, *B. U. S. G. S.* No. 71, a valuable book of reference.

[2] Lyell and Dawson, *Q. J. G. S.* ix. (1853), p. 58. J. W. Dawson, "Synopsis of the air-breathing animals of the Palæozoic (rocks) in Canada up to 1894," *Trans. Roy. Soc. Canada.* 1894, sect. iv. pp. 71-88. The list includes a few examples not obtained from the tree trunks, and from Cape Breton and Pictou, likewise a small number of arachnids and insects from the so-called "Devonian" plant-bearing strata of St. John, N.B. The latter, as has already been pointed out, are claimed by palæobotanists as undoubtedly belonging to the Coal-measures.

[3] See British Museum "Catalogue of Fossil Reptilia and Amphibia," Part iv. by R. Lydekker, 1890.

[4] Miall. *Brit. Assoc.* 1873, 1874.

part Permian, has furnished a considerable number of genera and species of labyrinthodonts and fishes.[1] Marsh has described a series of footprints from the middle Coal-measures of South-eastern Kansas, some of which, he thought, were probably amphibian, others lacertilian or even deinosaurian. The most abundant of the larger prints have four toes on both fore and hind feet, while in another type the fore-feet had five toes and those behind only four.[2]

It has been hitherto the general experience of geologists that fossil plants do not serve so well for purposes of geological classification as fossil animals (pp. 832, 839, 848).[3] But there can be no doubt that certain broad stratigraphical subdivisions may be based on the evidence of plant remains, and the attempts in this direction that have been made in recent years with regard to the stratigraphy of the Carboniferous system, encourage the hope that when the fossil floras are more minutely investigated they may afford valuable assistance in stratigraphical determinations. It is nearly half a century since Geinitz (1856) distinguished five zones in the German Carboniferous formations, each characterised by its own facies of vegetation. 1st. The Culm with *Lepidodendron veltheimianum, Calamites transitionis*,[4] followed by the remaining four zones, which comprise the productive Coal-measures; viz. 2nd, the zone of Sigillarias; 3rd, the zone of Calamites; 4th, the zone of Annularia; and 5th, the zone of Ferns.[5] Twenty years later Grand' Eury gave a much more elaborate classification of the Carboniferous system of Central France, according to the succession of vegetation, as shown in the following table:[6]—

Supra-Carboniferous Flora, simpler and less rich than that below, showing a passage into the Permian flora above, characterised by a rapid diminution of *Alethopteris, Odontopteris xenopteroides, Dictyopteris, Annularia, Sphenophyllum*. The Calamites are represented by abundant individuals of *C. varians* and *C. Suckowii*, also *Asterophyllites equisetiformis;* the ferns by *Pecopteris cyatheoides, P. hemitelioides, Odontopteris minor, O. Schlotheimii*, several species of *Neuroptepis*, &c.; the Sigillarias by *S. Brardii, S. spinulosa*, and *Stigmaria ficoides; Cordaites* by numerous narrow-leaved forms; the Calamodendra by a prodigious abundance of some species, *e.g. Calamodendron bistriatum*,

[1] C. Feistmantel, *Archiv. Naturw. Landesdurchforsch. Böhmen*. v. No. 3 (1883), p. 52; and especially the great monograph of A. Fritsch, "Fauna der Gaskohle Böhmens," 1879 and subsequent years.

[2] *Amer. Journ. Sci.* xlviii. (1894), p. 81.

[3] Some palæobotanists, however, hold a contrary opinion. See, for instance, Mr. Kidston, *Proc. Roy. Phys. Soc. Edin.* xii. (1893), p. 184. Possibly the reason for the prevalent belief is to be found, as he suggests, in the fact that fossil plants have been less fully studied than fossil animals, especially from a stratigraphical point of view.

[4] Now known as *Asterocalamites scrobiculatus.*

[5] 'Geognost. Darst. Steink. Sachsen,' 1856, p. 83; 'Die Steinkohlen Deutschlands,' 1865, i. p. 29.

[6] 'Flore Carbonifère du Département de la Loire et du Centre de la France,' Cyrille Grand' Eury, *Mem. Sav. Etrangers*, xxiv. (1877). This table is here given as the fullest available synopsis of the classification of the Carboniferous system of a single country on the basis of fossil plants. But further and more extended research is required before a scheme of arrangement can be perfected that may be capable of general application.

Calamites cruciatus, Asterophyllites [illegible]; the conifers by *Walchia piniformis* and some others.

Upper Coal Flora (properly so called). Calamites often abundant (*Calamites Cistii, C. Suckowii, C. cannaeformis, C. cruciatus, Asterophyllites hippuroides, Macrostachya infundibuliformis* very common), *Annularia brevifolia*, and *A. longifolia* common throughout, *Sphenophyllum oblongifolium*. Ferns richly developed, particularly of the genera *Pecopteris* (*P. unita, arguta, polymorpha*, and especially *Schlotheimii*); *Odontopteris* (*O. Reichiana, Brardii, minor, xenopteroides*, the last extremely abundant); *Caulopteris macrodiscus, Alethopteris Grandini* in great profusion, *Callipteridium* (*C. ovatum, gigas, densifolium*, common). Lepidodendra have almost disappeared; Sigillariae are not uncommon (*S. rhytidolepis, S. Brardii*), with *Stigmariopsis* and *Syringodendron*. *Cordaites* occurs in great abundance; the conifers are represented by *Walchia piniformis* and a few other species.

Upper Coal Flora (Lower Zone, *Flore du terrain houiller sous-supérieure*). Calamites and Asterophyllites abundant in individuals and species (*C. Suckowii, Cistii, cannaeformis, varians, approximatus, A. rigidus, grandis, hippuroides*), *Annularia radiata, Sphenophyllum*. Among the ferns there are few true sphenopterids, but *Neuropteris* is common (*N. flexuosa, auriculata*), also *Odontopteris* (*O. Reichiana, Schlotheimii*), *Pecopteris* (*P. arborescens, pulchra, Candolliana, villosa, oreopteridia, caudata, aspidioides, elegans*), *Caulopteris, Psaronius*. Lepidodendra are few (*L. Sternbergii, elegans, Lepidostrobus subvariabilis, Lepidophloios laricinus, Knorria Selloni, Lepidophyllum majus*). Sigillarioid forms are likewise on the wane when compared with their profusion below (*Sigillaria elliptica, Candollii, tessellata, elegans, graeseri, Brardii, spinulosa; Syringodendron cyclostigma, distans; Stigmaria ficoides* abundant). *Cordaites*, however, now becomes the dominant group of plants, but with a somewhat different facies from that which it presents in the middle Coal-measures (*C. borassifolius, C. principalis, Dorycordaites Brandlingii, Cardiocarpus emarginatus, Gutbieri, major, ovatus*). *Calamites cruciatus* makes its appearance, also *Walchia piniformis*.

Middle Coal Flora (Upper Zone, *Supra-moyenne*). Calamites numerous (*C. Suckowii, Cistii, cannaeformis, ramosus; Asterophyllites foliosus, longifolius, grandis, rigidus; Annularia radiata, brevifolia; Sphenophyllum saxifragaefolium, Schlotheimii, emarginatum, majus*). Ferns represented by *Sphenopteris* (*S. latifolia, irregularis, trifoliolata, cristata*, &c.), *Pecopteris* (maximum of this genus), *Pecopteris* (*P. abbreviata, villosa, Cistii, oreopteridia*, &c.), *Caulopteris, Neuropteris*, and other genera. Lepidodendra are not infrequent (*Lepidodendron aculeatum, Sternbergii, elegans, rimosum; Lepidostrobus variabilis; Lepidophloios laricinus, Lepidophyllum majus*), and various *Lycopodites*. The proportion of *Sigillaria* is always large (*S. Cortei, intermedia, Sillimanni, tessellata, cyclostigma, alternans, Brongniarti, Stigmaria ficoides, minor*). *Pseudosigillaria* is abundant, especially *P. monostigma*. *Cordaites* appears in some places abundantly (*C. borassifolius, Artisia transversa, Cladiscus schnorrianus*), and its fruits are numerous and varied (*Cardiocarpus emarginatus, orbicularis, ovatus*).

Middle Coal Flora (properly so called), characterised above all by the dominant place of the Sigillarioids, which now surpass the lepidodendroids and form the main mass of the coal-seams. The genus *Sigillaria* here attains its maximum development (*S. Graeseri, angusta, scutellata, intermedia, elongata, notata, alternans, rugosa, reniformis, lepidodendrifolia*, and many more; *Pseudosigillaria striata, rimosa, monostigma; Stigmaria ficoides, minor*). Lepidodendroids are large and frequent (*Lepidodendron aculeatum, obovatum, undulatum, rimosum, Sternbergii, elegans; Lepidophloios laricinus; Ulodendron majus, minus; Halonia tuberculata, tortuosa, regularis; Lepidophyllum majus; Lepidostrobus variabilis*). The ferns are abundant and varied; the Sphenopterids include many species, of which *Sphenopteris Hoeninghausii* and *tenella* are common, also *S. Bronni, Schlotheimii, trifoliolata, coralloides, furcata, elegans*; *Alethopteris* is very plentiful (*A. lonchitica, Serlii, Mantelli, heterophylla*); also *Lonchopteris Bricei* and *L. Roehlii*; *Pecopteris, Pecopteris, Megaphyton, Neuropteris* (*N. flexuosa, Loshii, tenuifolia*

folia, gigantea), *Cyclopteris, Aulacopteris.* The calamites are widely diffused and abundant, especially *Calamites dubius, undulatus, ramosus, decoratus, Steinhaueri; Asterophyllites subhippuroides, grandis, longifolius; Volkmannia binneyana; Sphenophyllum* seems here to reach its maximum, characteristic species being *S. emarginatum, saxifragæfolium, erosum, dentatum, truncatum, Schlotheimii.* Some coals and shales abound with *Cardiocarpus*, also *Trigonocarpus*, and *Nöggerathia.*

Middle Coal Flora—(Lower Zone, *Flore houillère sous-moyenne*).—Lepidodendroids are characteristically abundant and varied (*Lepidodendron aculeatum, obovatum, crenatum, Haidingeri, undulatum, longifolium;* and *Lepidophloios laricinus, intermedius, crassicaulis; Ulodendron*, abundant in England, *U. dichotomum, punctatum, majus, minus*, &c.; *Halonia tortuosa, regularis*, &c.). Sigillarioids are numerous (*Sigillaria oculata, elegans, scutellata, elongata, mamillaris, alveolaris, reniformis; Stigmaria ficoides, minor, stellata, reticulata; Dictyoxylon, Lyginodendron*). Calamites abound (*C. cannæformis, Suckowii, Cistii, decoratus, approximatus; Asterophyllites subhippuroides, longifolius; Volkmannia polystachya*). Ferns likewise form a notable part of the flora especially sphenopterids (*Sphenopteris latifolia, acutifolia, elegans, dissecta, furcata, Gravenhorstii, nervosa, muricata, obtusiloba, trifoliata*); also *Prepecopteris silesiaca, oxyphylla, Glockeri, dentata; Megaphyton majus; Pecopteris ophiodermatica* and other similar forms. The neuropterids become abundant (*Neuropteris heterophylla, Loshii, gigantea, tenuifolia; Cyclopteris obliqua; Alethopteris lonchitica*, &c.). The abundant *Cordaites* of the higher measures are absent, though the fruit *Carpolithus* occasionally occurs.

Infra Coal-measure Flora—(Millstone grit, *l'étage infra-houiller*), characterised essentially by lepidodendroids and stigmarias.—*Lepidodendron aculeatum, obovatum crenatum, brevifolium, caudatum, carinatum, rimosum, volkmannianum; Ulodendron punctatum, ellipticum, majus; Halonia tuberculosa; Lepidophloios intermedius, laricinus. Sigillaria* is not very common, but *S. oculata, alveolata* (Stern.), *Knorrii, trigona, minima*, and other species occur. The ferns are more varied than in older parts of the system, sphenopterids being the dominant types (*Sphenopteris distans, elegans, tridactylites, furcata, dissecta, rigida, divaricata, linearis, acutiloba*, &c.). The genus *Pecopteris* is represented by a few species. *Neuropteris* is comparatively rare (*N. Loshii, tenuifolia*), *Alethopteris* appears in the widespread species *A. lonchitica*, and a few others. Calamites are not relatively abundant (*Calamites undulatus, Steinhaueri, communis, cannæformis, Cistii; Asterophyllites foliosus*, &c.).

Flora of the Upper Greywacke.—Lepidodendroids are the prevalent forms (*Lepidodendron carinatum, polyphyllum, volkmannianum, rugosum, caudatum, aculeatum, obovatum; Halonia tetrasticha, regularis; Ulodendron ovale, commutatum*). *Stigmaria* in several species occurs, sometimes abundantly; but *Sigillaria* is rare (*S. undulata, Voltzii, costata, subelegans, venosa, Guerangeri, verneuillana*). Calamites are not infrequent (*C. Roemeri, Voltzii, cannæformis*, &c.). The ferns are chiefly sphenopterids (*Sphenopteris dissecta, elegans, Gersdorfii, distans, tridactylites, schistorum; Cyclopteris tenuifolia, Haidingeri, flabellata; Prepecopteris aspera, subdentata; Neuropteris heterophylla, Loshii*).

Flora of the Culm, characterised by the abundance of lepidodendroids of the type of *L. veltheimianum* (with *Knorria imbricata*), by the number of *Bornia transitionis*, associated with *Calamites Roemeri, Stigmaria ficoides* (and other species), and by the abundance of the palæopterid ferns (*Palæopteris Machaneti, antiqua, dissecta, Calymmatotheca* (*Sphenopteris*) *affinis* (Fig. 401); *Cardiopteris frondosa; Rhodea divaricata, elegans, moravica; Sphenopteris Göpperti, Schimperi*, &c.).

Carboniferous Limestone Flora.—The palæopterid ferns reach a maximum (*Palæopteris inæquilatera, lindseæformis, polymorpha, frondosa, Calymmatotheca affinis*). Sphenopterid forms are found in *Sphenopteris bifida, lanceolata, confertifolia.* The old genus *Cyclostigma* here disappears (*C. minuta, Nathorstii*). The more characteristic lepidodendroids are *Lepidodendron weikianum, veltheimianum, squamosum; Knorria*

imbricata, acicularis. The flora includes also *Stigmaria ficoides, rugosa; Bornia transitionis; Asterophyllites elegans*, &c.

This subject has increasingly engaged the attention of palæobotanists during recent years. The late D. Stur, whose labours in the Carboniferous flora were so fruitful, correlated the Carboniferous system of Britain with that of Central Europe mainly by means of the plants. He regarded the Coal-measures of Wales and the west of England generally as equivalent to the higher series of Germany, those of central and northern England and Scotland as equivalent to the lower series, both of these series being represented in Lancashire.[1] The question has since been taken up with much zeal and success by Mr. Kidston, with reference to the British Carboniferous flora, and he is still engaged in the investigation. A preliminary statement of his results was published by him in 1893, to which further reference will be made in the sequel.[2] Mr. D. White has likewise insisted upon the stratigraphical succession of floras in the southern anthracite coal-field of Pennsylvania. He thinks that the plants of the Pottsville Formation in that field "exhibit a rapid development and series of changes or modifications, which if treated with great systematic refinement are of high stratigraphical value."[3]

§ 2. Local development.

The European development of the Carboniferous system presents certain well-marked local types, which bring clearly before the mind some of the successive geographical features of the time. During the earlier half of the Carboniferous period, there still lay much land towards the north and north-west of the present European area, whence a continuous supply of sandy and muddy sediment was derived. A sea of moderate depth and clear water extended from the Atlantic across the site of Central Ireland, the heart of England and Belgium into Westphalia. The southern margin of this ancient Mediterranean was probably formed by the ridge of older Palæozoic and crystalline rocks, which, extending from the west of England into the Boulonnais, and from Brittany into Central France, sweeps eastward by the uplands of the Ardennes, Hundsrück, Taunus, and Thuringer Wald into Saxony and Silesia. In the deeper and clearer water, massive beds of limestone accumulated; but towards the land, at least on the north side of the sea, there was an increasingly abundant deposit of sand and mud, with occasional seams of coal and sheets of limestone. The whole region underwent slow subsidence and infilling of sediment, until at last vast marshes and jungles occupied tracts that had been previously sea. By degrees, the lower parts of the surrounding land were likewise submerged beneath the accumulating coal-growths, which consequently spread over the sinking areas. Hence, while across the central portions of the Carboniferous region the normal succession of strata presents a lower marine division, consisting mainly of limestone, and an upper brackish-water division, composed of sandstones, shales, and coal-seams, the marginal tracts show hardly any limestone, some of them indeed, as in Central France, containing only the highest part of the upper division.

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[1] *Jahrb. K. K. Geol. Reichsanst*, 1889.

[2] *Trans. Roy. Soc. Edin.* xxxv. (1890-91), pp. 63, 391 419; xxxvii. (1893), p. 307. *Proc. Roy. Phys. Soc. Edin.* xii. (1893), p. 219.

[3] *20th Ann. Rep. U.S. G. S.* (1900), pp. 749-918.

The British Isles.[1] The general sequence just referred to is well illustrated in the structure of the Carboniferous tracts of Britain, which being sufficiently extensive to contain more than one type of the system, cast interesting light on the varied geographical conditions under which the rocks were accumulated. As the land, whence the chief supplies of sediment were derived, rose mainly to the north and north-west, while the centre of England and Ireland lay under clear water of moderate depth, the sea shallowed northwards into Scotland, and its bottom was covered with constantly accumulating banks of sand and sheets of mud. Hence vertical sections of the Carboniferous system of Britain differ greatly according to the districts in which they are taken. The adjoined table may be regarded as expressing the typical subdivisions which can be recognised, with modifications, in all parts of the country.

3. Coal-measures	Upper series of red and grey sandstones, clays, and sometimes breccias, with occasional seams and streaks of coal and Spirorbis limestone. This group contains workable coals in the Bristol and Somerset (Radstock and Farrington), South Wales, and Forest of Dean fields, but in other parts of England is represented by red shales without workable coals, described on p. 1049.[2]
	Middle or chief coal-bearing series of sandstones, clays, and shales, with numerous workable coal-seams (p. 1048).
	Lower Coal-measures or Gannister beds. Flagstones, shales, and thin coal-seams, with in some districts hard siliceous pavements (gannister). Many of the characteristic plants of the Middle Coal-measures are here absent.[3]
2. Millstone Grit	Grits, flagstones, and shales, with thin seams of coal and occasional layers of fossiliferous limestone and shale. The plants are generally scarce and badly preserved, but are of Coal-measure forms and specifically distinct from those of the strata below. Its limestones are marine and the fossils contained in them are generally common to the Carboniferous Limestone below (p. 1047).
	Yoredale Group of shales, limestones, and grits, passing laterally into the thick limestones of the centre and south-west of England. The limestones and calcareous shales contain Carboniferous Limestone fossils. The dark shales and sandstones yield plants which can be distinguished from those of the true Coal-measures. The prevalent forms are *Lepidodendron veltheimianum*, *Sphenopteris dicksonioides*, *S. Linkii*, *S. [illegible]*, *S. [illegible]*, *Adiantites*

[1] For detailed information regarding British Carboniferous rocks and fossils the student may consult, among early works, Phillips' 'Geology of Yorkshire,' 1836, and papers by Prestwich (*Geol. Trans.* 2nd ser. v.), and Sedgwick (*op. cit.* iv. *Q. J. G. S.* viii. *Proc. Geol. Soc.* ii.). Of later date are memoirs by Binney (*Q. J. G. S.* ii. xviii.), Kirkby (*op. cit.* xxxvi.), Davis and Lees, 'West Yorkshire,' 1878; G. H. Morton, numerous papers in *Proc. Liverpool Geol. Soc.*; Hull's 'Coal Fields of Great Britain.' The *Memoirs of the Geological Survey* will be found to supply much detailed information for the various Carboniferous tracts of Britain; see, for example, the "Geology of the Yorkshire Coal Field," by Messrs. Green and Russell, "Geology of Flint and Mold," by A. Strahan, and the Memoir on the South Wales Coal-field, of which several parts have appeared.

The proposal to arrange the stratigraphical subdivisions of the British Carboniferous system on the basis of a study of the zonal distribution of the fossil plants, has been supplemented by the endeavour to work out the same idea with reference to the animal remains, and some progress has been made in the subject. See Garwood and Marr, *Geol. Mag.* 1895, p. 550, also 1896, p. 46. Wheelton Hind, *op. cit.* 1896, p. 255; 1897, pp. 159, 205; 1898, p. 61. G. H. Morton, *op. cit.* 1897, p. 132. A committee for the consideration of the question has been appointed by the British Association, *Reports*, 1896, 1897, 1898, pp. 371-376.

1. Carboniferous Limestone series	*Machanekii* and *Archæopteris Tschermaki*, appear to be restricted to the Carboniferous Limestone series (p. 1042).[1] Thick (Scaur or Main) limestone in south and centre of England and Ireland, passing northwards into sandstones, shales, and coals with limestones (abundant corals, polyzoa, brachiopods, lamellibranchs), of which a more detailed account follows this table. Lower Limestone Shale of south and centre of England (marine fossils like those of overlying limestone). The Calciferous Sandstone group of Scotland (marine, estuarine, and terrestrial organisms), which probably represents the Scaur Limestone and Lower Limestone Shale, and graduates downward insensibly into the Upper Old Red Sandstone, is described at p. 1042.

1. Carboniferous Limestone Series and local equivalents.—In the south-west of England, and in South Wales, the Carboniferous system passes down conformably into the Old Red Sandstone. The passage beds consist of yellow, green, and reddish sandstones, green, grey, red, blue, and variegated marls and shales, sometimes full of terrestrial plants. They are well exposed on the Pembrokeshire coasts, marine fossils being there found even among the argillaceous beds at the top of the Red Sandstone series. They occur with a thickness of about 500 feet in the gorge of the Avon near Bristol, but show less than half that depth about the Forest of Dean. At their base there lies a bone-bed containing abundant palatal teeth. Not far above this horizon plant-bearing strata are found. Hence these rocks bring before us a mingling of terrestrial and marine conditions. In Yorkshire, near Lowther Castle, Brough, and in Ravenstonedale, alternations of red sandstones, shales, and clays, containing *Stigmaria* and other plants, occur in the lower part of the Carboniferous Limestone. Along the eastern edge of the Silurian hills of the Lake District, at the base of the Pennine escarpment and round the Cheviot Hills, a succession of red and grey sandstones, and green and red shales and marls with plants, underlies the base of the Carboniferous Limestone, It is highly probable, however, that these red strata form merely a local base, and occur on many successive horizons; so that they should be regarded not as marking any particular period, but rather as indicating the recurrence or persistence of certain peculiar littoral conditions of deposit during the subsidence of the land (p. 652). Farther north, in the southern counties of Scotland, the Upper Old Red Sandstone, with its characteristic fishes, graduates upward into reddish and grey sandstones with Carboniferous plants.

In Devon and Cornwall a type of the Carboniferous system is found, which, though it does not occur elsewhere in Britain, has been ascertained to reappear and to have a wide extension in Central Europe. It presents a thick series of well-bedded grits, sandstones, shales, often dark grey, with occasional thin limestone and radiolarian cherts, and passes down conformably into upper Devonian strata. Though much contorted and faulted, like the Devonian formations of the same region, this arenaceous and shaly series has yielded a sufficiently large number of recognisable fossils to show its geological position. The plants resemble generally those found in the Calciferous Sandstone series of Scotland. The animal remains include species of *Orthoceras*, *Glyphioceras* (*Goniatites*), *Prolecanites* (*Goniatites*), *Nomismoceras* (*Goniatites*), *Pericyclus* (*Goniatites*), *Posidonomya* (*P. Becheri*), *Chonetes*, *Spirifer* (*S. Urei*), *Productus* (*P. plicatus*, *P. concentricus*), *Orthis Michelini*, *Phillipsia*, *Griffithides*, *Proëtus*, *Cœlacanthus elegans*, *Elonichthys Aitkeni*, &c., an assemblage that also points to a position low down in the Carboniferous system. The siliceous bands or cherts, and some of the softer shales have yielded 23 genera of radiolaria.[2] This series of strata is known as the Culm-

[1] The plants here mentioned are given on the authority of Mr. Kidston in his paper in *Proc. Roy. Phys. Soc. Edin.* cited above on p. 1037.

[2] G. J. Hinde and H. Fox, *Q. J. G. S.* li. (1895); *Trans. Devon. Assoc.* xxviii. (1896), p. 774. Gen. M'Mahon, *Geol. Mag.* 1890, p. 106.

measures, and the name Culm has been adopted as the designation of this type of Lower Carboniferous rocks abroad. Bands of tuff, diabase, &c., mark contemporaneous volcanic activity during the deposition of the Devonshire Culm.[1]

In the south and south-west of England, and in South Wales, the base of the Carboniferous system consists of certain dark shales known as Lower Limestone Shale, in which a few characteristic fossils of the Carboniferous Limestone occur. The distinctive lamellibranch is *Modiola Macadamii.* These basement beds vary up to rather more than 400 feet in thickness. They are overlain conformably by the thick mass of limestone, which in Britain and Belgium forms a characteristic member of the Carboniferous system.

The name Carboniferous Limestone (or Mountain Limestone) was given by Conybeare to the thick mass of limestone which in the south-west of England is interposed between the Old Red Sandstone and the Coal-measures. As the geological structure of the country came to be more fully known, the limestone was found to pass laterally into sandy and argillaceous strata. The term Carboniferous Limestone Series is now applied to this division of the system, which attains its greatest thickness in the north, though the limestone there forms a subordinate part of the whole series. Towards the south, on the other hand, the limestone increases in dimensions till it practically constitutes the entire thickness of the series. In the Pennine chain, which forms the axis of the north of England, the Carboniferous Limestone series attains a thickness of nearly 4000 feet, yet this is not its entire depth, for its base is not seen. Of this great thickness the lowest visible 1600 feet consist of limestone. Traced southward this limestone increases in magnitude, till in the Mendip Hills it attains a thickness of about 3000 feet. Followed, on the other hand, towards the north, the calcareous part of the series diminishes in Scotland to a few thin seams of limestone, the main mass of rock consisting of sandstone and shale with seams of coal and ironstone. The Pennine chain appears to have been the area of maximum depression during the early part of the Carboniferous period in England. The great and rapid variations in thickness of the limestone may indicate inequalities in the downward movement, and perhaps to some extent irregularities in the growth of corals and the accumulation of calcareous débris. The great mass of 3000 feet of limestone in the Mendip Hills dwindles down to less than 400 feet in the Forest of Dean, a distance of only some 30 miles. The thickness sinks at Abergavenny, in the east of Glamorganshire, to hardly more than 100 feet of thin seams of limestone and shale. Thirty miles to the south, at Barry, it has increased to more than 1000 feet, while only 20 miles farther west, at Porthcawl, it is estimated to be as much as 4500. The whole of the Carboniferous rocks of South Wales thicken towards the south and west. It is therefore surprising to find that towards the western limits of the region the Carboniferous Limestone on the coast of Pembrokeshire disappears altogether,[2] and the Coal-measures come immediately next to the older Palæozoic rocks. This structure, however, is not improbably due to gigantic overthrusts, whereby the Carboniferous Limestone has been concealed.

Where typically developed, the Carboniferous Limestone is a massive well-bedded limestone, chiefly light bluish-grey in colour, varying from compact homogeneous to distinctly crystalline in texture, and rising into ranges of hills, whence its original name "Mountain Limestone." It is sometimes, especially near Bristol and along the north

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[1] De la Beche, 'Geology of Cornwall,' &c. Ussher, *Geol. Mag.* 1887, p. 10; *Proc. Somerset Arch. Nat. Hist. Soc.* xxxviii. (1892), pp. 111-219.

[2] De la Beche (*Mem. Geol. Surv.* i. p. 112) states that the limestone is there overlapped by the Coal-measures. But the complicated structure of the ground was not realised in his day. This region is now being mapped in detail by the Geological Survey, and its structure will soon be better understood. See the published maps and the successive Parts of the Memoir on the South Wales coal-field.

crop of the South Wales coal-field, distinctly oolitic[1] and often contains occasional scattered irregular nodules and nodular beds of dark chert (phtanite).[2] Though it is abundantly fossiliferous, little has yet been done in working out in detail the successive life-zones of this great mass of rock, as has been performed so well for the corresponding limestone series of Belgium.[3] *Productus giganteus* and *P. cora* have been claimed as distinctive of the thick limestone, but the former ascends far above that platform. Some of the other organisms certainly range through the whole of the Carboniferous Limestone series, even up into the Coal-measures, such as *Productus semireticulatus*, *P. scabriculus*, *Edmondia rudis*, *Lithodomus* (*Modiola*) *lingualis* and species of *Lingula*, indicating a long continuity of the same general geographical conditions. Some portions of the limestone are made mainly of bunches and sheets of coral (*Lithostrotion*, *Phillipsastræa*, &c.), while solitary cup corals (*Zaphrentis*, *Cyathophyllum*, &c.) are often profusely abundant. Many of the sheets of calcareous material consist almost entirely of the joints and broken stems of crinoids, mingled with valves of brachiopods and lamellibranchs, gasteropods and cephalopods of the genera already enumerated, while occasional teeth and spines of the elasmobranch fishes are dispersed through the rock. Such deposits point to clear and moderately deep water, into which little or no ordinary sediment was carried from the land, but where a prolific marine fauna gradually built up masses of limestone hundreds or even thousands of feet in thickness. Mr. Tiddeman has described under the name of "reef-knolls" certain mound-like aggregations of calcareous matter, which he supposes to be partly of the nature of coral-reefs.[4]

On a weathered surface of the limestone the fossils commonly stand out conspicuously, as their more largely crystalline calcite enables them to resist the atmospheric influences better than the fine detrital material in which they lie. Even, however, limestones which may appear to the naked eye destitute of fossils and structureless, may be shown by the examination of thin slices of them under the microscope to be crowded with organic remains, both entire minute forms (spicules, foraminifera, radiolaria, &c.) and fragments of larger kinds. Diversities of colour and lithological character occur, whereby the bedding of the thick masses of limestone can be distinctly seen. Here and there, a more markedly crystalline structure has been superinduced; while along lines of principal joints the rock on either side for a breadth of 20 or 30 fathoms is occasionally converted into yellowish or brown dolomite or "dunstone" (see p. 426).

In England and in Ireland interesting evidence exists of submarine volcanoes during the time of the Carboniferous Limestone. In Derbyshire sheets of basalt-lava and tuff, locally termed "toadstone," together with some volcanic vents filled with agglomerate

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[1] In Glamorganshire a band of white oolite 40 feet thick lies in the middle of the main limestone, while some parts of the lower limestone are also oolitic.

[2] The chert bands of the Carboniferous Limestone have been shown by Dr. Hinde to be largely composed of spicules of siliceous sponges, *Geol. Mag.* 1887, p. 435; and 'British Palæozoic Sponges,' *Pal. Soc.* for 1887, 1888. He has also described similar beds from the Permo-Carboniferous rocks of Spitzbergen, *Geol. Mag.* 1888, p. 241.

[3] As examples of recent careful papers descriptive of the Carboniferous Limestone and the distribution of its fossils, reference may be made to two memoirs by the late G. H. Morton on the Vale of Clwyd and on Anglesey, *Proc. Liverpool Geol. Soc.* 1898 and 1901; and to the memoir by Dr. Wheelton Hind and Mr. J. A. Howe, *Q. J. G. S.* lvii. (1901), pp. 347-402.

[4] *Brit. Assoc.* 1889, p. 600; 1900, p. 740; *Geol. Mag.* 1901, p. 20. Mr. Marr regards them as probably due to local thickening as a consequence of rupture and overthrust (*Q. J. G. S.* lv. 1899, p. 327; see also Lamplugh, *op. cit.* lvi. 1900, p. 11). W. Hind and J. Howe, *op. cit.* lvii. (1901), p. 361. The original reef-knolls described by Mr. Tiddeman from the Clitheroe district appeared to me to be due to the irregular aggregation of submarine organic débris *in situ*, though I could not detect any true reef-structure.

and tuff, mark one of the centres of eruption.[1] Another is to be seen at the south end of the Isle of Man.[2] A third appears in Somerset[3] (Fig. 334), and a fourth in Southern Devonshire.[4] Two widely separated volcanic tracts have been found in Ireland, one in King's County, the other, on a much larger and more diversified scale, in Limerick.[5] It is in Scotland, however, as will be immediately referred to, that the most remarkable proofs of abundantly active Carboniferous volcanoes have been preserved.

In the Carboniferous areas of the south-west of England and South Wales, the limits of the Carboniferous Limestone are well defined by the Lower Limestone Shale below, and by the Farewell Rock or Millstone Grit above. In the Pennine area, however, the massive limestone passes laterally into a series of shales, limestones, and sandstones, known as the Yoredale Group.[6] These cover a large area and attain a great thickness. In North Staffordshire they are 2300 feet thick. In Lancashire they attain still greater dimensions, Mr. Hull having there found them to be no less than 4500 feet thick. Both the lower or main (Scaur) limestone and the Yoredale group pass northwards into sandstones and shales with coal seams. In Northumberland, the Carboniferous Limestone series has been grouped into the following subdivisions:—

Upper Calcareous group, from the base of the Millstone grit to the Great Limestone, 350-1200 feet.
Lower Calcareous group, from the Great Limestone to the bottom of the Dun or Redesdale Limestone, 1300-2500 feet.
Carbonaceous group, Scremerston coals, from the Dun Limestone to the top of the Fell Sandstone, 800-2500 feet.
Fell Sandstone, 500-1600 feet.
Tuedian or Cement Stone group, 500-1500 feet.
Basement conglomerate.

These subdivisions are not all fully developed in any one district, but the average thickness of the whole is at least as great as in districts farther south.

Traced northwards into Scotland, the Carboniferous Limestone series undergoes a still further petrographical and palæontological change. Its massive limestones dwindle down, and are replaced by thick courses of yellow and white sandstone, dark shale, and seams of coal and ironstone, among which only a few thin sheets of limestone are to be met with. Scottish geologists have named the lower part of their Carboniferous system the Calciferous Sandstone series. It passes down conformably into the Upper Old Red Sandstone, and graduates upwards into the base of what is known as the Carboniferous Limestone series of Scotland. There can be no doubt, however, that it is really the stratigraphical equivalent of the greater part of the Carboniferous Limestone of England, including both the Lower Limestone Shale and the Yoredale rocks.[7] The Calciferous Sandstones present two distinct types of sedimentation. In the more usual of these, known as the Cement-Stone group, the strata consist of thin-bedded white, yellow, and

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[1] 'Ancient Volcanoes of Great Britain,' chap. xxix. and authorities there cited. H. Arnold Bemrose, *Q. J. G. S.* l. (1894), p. 603; lv. (1889), pp. 224, 239, 548.

[2] J. Horne, *Trans. Geol. Soc. Edin.* ii. (1874), p. 332. B. Hobson, *Q. J. G. S.* xlvii. (1891), p. 432; *Yn Lioar Manninagh*, Douglas, January 1892, p. 337. A. G., 'Ancient Volcanoes of Great Britain,' chap. xxix. The geology of this island has been worked out in detail by Mr. Lamplugh for the Geological Survey, and his memoir on the Geology of the Isle of Man is now in the press.

[3] *Summary of Progress of Geol. Surv.* for 1898, p. 104.

[4] De la Beche, 'Report on the Geology of Cornwall,' &c. (1839), p. 119. F. Rutley, "The Eruptive Rocks of Brent Tor," *Mem. Geol. Surv.* (1878). *Q. J. G. S.* xxxvi. (1880), p. 286. General M'Mahon, *op. cit.* l. (1894), p. 338.

[5] 'Ancient Volcanoes of Great Britain,' chap. xxx., and references there given.

[6] Dr. Wheelton Hind, *Geol. Mag.* 1897, pp. 159, 205.

[7] See W. Gunn, *Geol. Mag.* 1898, p. 342.

green sandstones, grey, green, blue, and red clays and shales, with thin bands of pale argillaceous limestone or cement-stone. Seams of gypsum occasionally appear. These deposits are, on the whole, singularly barren of organic remains. They seem to have been laid down with great slowness, and without disturbance, in enclosed basins, which, as a rule, were not well fitted for the support of animal life, though occasional ostracod limestones and other traces of organisms may be noted, while fragmentary plants serve to show that the adjoining slopes were covered with vegetation. The cement-stone group in Central Scotland is overlain with an important volcanic platform, to which reference will immediately be made, but in the southern counties a corresponding platform lies below it. The second type of the Calciferous Sandstones is well developed in the Lothians and Fife. It may there be seen lying upon the volcanic rocks that cover the normal cement-stone group, of the upper part of which it may be the equivalent. It is known as the Burdie House or Oil-shale group, and consists of yellow, grey, and white sandstones, with blue and black shales, clay-ironstones, limestones, "cement-stones," and occasional seams of coal. The sandstones form excellent building stones, the city of Edinburgh having been built of them (p. 165). Some of the shales are so bituminous as to yield, on distillation, from thirty to forty gallons of crude petroleum to the ton of shale; they have consequently been largely worked for the manufacture of mineral-oil. The limestones are usually dull, grey or yellow, and close-grained, in seams seldom more than a few inches thick, and graduate by addition of clay and protoxide of iron into cement-stone; but occasionally they swell out into thick lenticular masses like the well-known limestone of Burdie House, so long noted for its remarkable fossil fishes. This limestone appears to be mainly made of the crowded cases of a small ostracod crustacean (*Leperditia Okeni*, var. *scoto-burdigalensis*). The coal-seams are few and commonly too thin to be workable, though one (Houston coal) has been mined in Linlithgowshire and several others in East Fife. The fossils of the Burdie House group indicate an alternation of fresh or brackish water and marine conditions. They include numerous plants, of which the most abundant are *Calymmatotheca* [*Sphenopteris*] *affinis* (Fig. 401), *Rhacopteris flabellata*, *Sphenopteris pachyrachis*, *S. bifida*, *Lepidodendron volkmannianum*, *L. veltheimianum*, *Lepidostrobus fimbriatus*, *Calamites*, *Stigmaria ficoides*, *Araucarioxylon*. Ostracod crustaceans, chiefly the *Leperditia* above mentioned, crowd many of the shales. With these are usually associated abundant traces of the presence of fish, either in the form of coprolites, or of scales, bones, plates, and teeth. The following are characteristic ganoid species: *Elonichthys striolatus*, *E. Robisoni*, *Rhadinichthys ornatissimus*, *Nematoptychius Greenockii*, *Eurynotus crenatus* (Fig. 400), *Rhizodus Hibberti*, *Megalichthys* sp. with the selachians *Gyracanthus formosus*, *Callopristodus* (*Ctenoptychius*) *pectinatus* and *Tristichius arcuatus*. At intervals throughout the group, marine horizons occur, usually as shale bands marked by the presence of such distinctively Carboniferous Limestone species as *Spirorbis carbonarius*, *Orbiculoidea* [*Discina*] *nitida*, *Lingula squamiformis*, *L. mytiloides*, *Murchisonia*, *Bellerophon decussatus*, *Goniatites*, *Orthoceras cylindraceum*, *O. sulcatum*. The marine bands increase in number in the East of Fife.[1]

One of the most singular features of the Lower Carboniferous rocks of Scotland is the prodigious abundance of intercalated volcanic rocks. So varied, indeed, are the characters of these masses, and so manifold and interesting is the light they throw upon volcanic action, that the region may be studied as a typical one for this class of phenomena. (See Book IV. Part VII. Sect. i.) Inland sections are abundant on the sides of the hills and in the stream-courses, while along the sea-shore the rocks have

[1] For descriptions of the Calciferous Sandstone group, see Maclaren, 'Geology of Fife and the Lothians'; also the Explanations to accompany the Maps of the Geological Survey of Scotland, particularly those on Sheets 14, 22, 23, 32, 33, and 34; the Memoir on Central and Western Fife (1900) and that on Eastern Fife (1902). T. Brown, *Trans. Roy. Soc. Edin.* xxii. (1861), p. 385. Kirkby, *Q. J. G. S.* xxxvi. p. 559.

been admirably exposed. Two great phases or types of volcanic action during Carboniferous time may be recognised: (1) Plateaux, where the volcanic materials, discharged copiously from many scattered openings, now form broad tablelands or ranges of hills, sometimes many hundreds of square miles in extent and 1500 feet or more in thickness; (2) Puys, where the ejections were often confined to the discharge of a small amount of fragmentary materials from a single independent vent, and where, when lavas and showers of ash were thrown out, they generally covered only a small area round the volcano which discharged them.[1]

The Plateau type of eruption was specially developed during the deposition of the Calciferous Sandstones. Its lavas consist of augite-olivine rocks (picrites, limburgites), basalts, andesites, and trachytes, while its necks or vents are filled with agglomerates, felsites, and in East Lothian, phonolites. Sheets of tuff are intercalated among the bedded lavas. The Puy type was, on the whole, of later date, reaching its chief development during the time of the Carboniferous Limestone. Its lavas are mostly basalts of various types, together with limburgites, picrites, and diabases. Tuffs and agglomerates are abundant, not infrequently containing organic remains (Figs. 330-333).

While the scattered vents of the puys, with their associated lavas and tuffs, occur on many horizons, the plateau-lavas occupy a tolerably definite position in the Calciferous Sandstones, though sometimes confined to the lower part of that group, sometimes ascending to the very base of the Carboniferous Limestone series. This volcanic zone forms an important feature in the geology of Southern Scotland. Composed of nearly horizontal sheets of andesite, diabase, and basalt, it extends from the Clyde islands on the west to Stirling on the east, and sweeps in high tablelands through Renfrewshire and Ayrshire. It reappears in East Lothian, and presents there some interesting and remarkably fresh trachytic lavas. In Berwickshire, Roxburghshire, and Kirkcudbright, the volcanic sheets already referred to intervene between the top of the Old Red Sandstone and base of the Cement stones, and extend across into the English border.

The Carboniferous Limestone series of Scottish geologists, probably represents the upper part of the Carboniferous Limestone of England. The main or Twelve fathom limestone of Yorkshire, which lies not far below the Millstone grit, has been traced into the north of Northumberland. The continuity of the outcrops is then interrupted by the Silurian ridge of the Lammermuir Hills, but if the identification of the uppermost Yoredale limestones of Northumberland with the lower limestones of the Scottish series near Dunbar be correct, it will follow that the so-called "Carboniferous Limestone series" of Scotland lies above the Yoredale rocks, and indicates a great northward development of the highest strata of the Carboniferous Limestone series of England.[2] As represented north of the Tweed, this series consists mainly of sandstones, shales, fire-clays, and coal seams, with a few comparatively thin seams of encrinal limestone. The thickest of these limestones, known as the Hurlet or Main limestone, is usually about 6 feet in thickness, but in the north of Ayrshire swells out to 100 feet, which is the most massive bed of limestone in any part of the Scottish Carboniferous system. It is made of marine organisms, some parts being sheets of lithodendron coral. Together with the shales overlying it, it is the great repository of the marine fossils of the series. It forms one of a group of limestone beds at the base of the series, and lies upon a seam of coal, in some places associated with pyritous shales, which have been largely worked as a source of alum. This superposition of a bed of marine limestone on a seam of coal is of frequent occurrence in Scotland.[3] Above these lower limestones comes a thick mass of

[1] The volcanic geology of this region is fully discussed in my 'Ancient Volcanoes of Great Britain,' and in the *Geol. Surv. Memoirs* cited on the previous page. See also *ante*, pp. 749-753, 755-764.

[2] W. Gunn, *Geol. Mag.* 1898, p. 342.

[3] For examples of remarkable alternations of marine and lagoon conditions, see *Geol. Survey Memoir*, "Eastern Fife," 1902.

strata containing many valuable coal-seams and ironstones (Lower or Edge Coals). Some of these strata are full of terrestrial plants (*Lepidodendron*, *Sigillaria*, *Stigmaria*, *Sphenopteris*, *Alethopteris*); others, particularly the ironstones, and the shales associated with the limestones and ironstones, contain marine shells, such as *Lingula*, *Orbiculoidea*, *Nuculana* (*Leda*), *Myalina*, *Euomphalus*. Numerous remains of fishes have been obtained, more especially from some of the ironstones and coals (*Gyracanthus formosus* and other fin-spines, *Megalichthys Hibberti*, *Rhizodus Hibberti*, with species of *Elonichthys*, *Acanthodes*, *Ctenoptychius*, &c.). Remains of labyrinthodonts have also been found in this group of strata, and have been detected even down in the Burdie House limestone. The highest division of the Scottish Carboniferous Limestone series consists of a group of sandstones and shales, with a few coal-seams, and three, sometimes more, bands of marine limestone. Although these limestones are each only about 2 or 3 feet thick, they have a wonderful persistence throughout the coal-fields of Central Scotland. As already mentioned (p. 651), they can be traced over an area of at least 1000 square miles, and they probably extended originally over a considerably greater region. The Hurlet limestone, with its underlying coal, can also be followed across a similar extent of country. Hence it is evident that, during certain epochs of the Carboniferous period, a singular uniformity of conditions prevailed over a large region of deposit in the centre of Scotland.

As above stated, a distinguishing feature of the Carboniferous Limestone series of Scotland is the abundance of its intercalated volcanic rocks of the puy type. They are well developed in the basin of the Forth and in North Ayrshire. The lavas and tuffs are interbedded among the ordinary sedimentary strata, and the tuffs are sometimes full of plants or of marine shells, crinoids, &c. (pp. 755, 756). The volcanic activity ceased before the time of the Millstone Grit.

The difference between the lithological characters of the Carboniferous Limestone series, in its typical development as a great marine formation, and in its arenaceous and argillaceous prolongation into the north of England and Scotland, has long been a familiar example of the nature and application of the evidence furnished by strata as to former geographical conditions. It shows that the deeper and clearer water of the Carboniferous sea spread over the site of the central and south-western parts of England; that land lay to the north, and that, while the whole area was undergoing subsidence, the maximum movement took place over the area of deeper water. The sediment derived from the north, during the time of the Carboniferous Limestone, seems to have sunk to the bottom before it could reach the great basin in which foraminifers, corals, crinoids, and mollusks were building up the thick calcareous deposit. Yet the thin limestone bands, which run so persistently among the lower Carboniferous rocks in Scotland, prove that there were occasional episodes during which sediment ceased to arrive, and when the same species of shells, corals, and crinoids spread northwards towards the land, forming for a time, over the sea-bottom, a continuous sheet of calcareous ooze, like that of the deeper water farther south. These intervals of limestone-growth no doubt point to times of more rapid submergence, perhaps also to other geographical changes, whereby the sediment was for a time prevented from spreading so far. It is further deserving of remark that the fossils in these thin upper limestones in Scotland, though specifically identical with those in the thick lower limestones and in the massive Carboniferous Limestone of central and south-western England, are often dwarfed forms, as if the conditions of life were much less favourable than where the thicker sheets of calcareous material were accumulated. The corals, for instance, are generally few in number and small in size, and the large *Productus* (*P. giganteus*) is reduced to a half or third of its usual dimensions.

Viewed as a whole, the Carboniferous Limestone series of the northern part of the British area contains the records of a long-continued but intermittent process of subsidence. The numerous coal seams, with their under-clays, may be regarded as surfaces of vegetation that grew in luxuriance on wide marine mud-flats. They mark pauses in

the subsidence. Perhaps we may infer the relative length of these pauses from the comparative thicknesses of the coal-seams. The overlying and intervening sandstones and shales indicate a renewal of the downward movement, and the gradual infilling of the depressed area with sediment, until the water once more shoaled, and the vegetation from adjacent swamps spread over the muddy flats as before. The occasional limestones serve to mark epochs of more prolonged or more rapid subsidence, when marine life was enabled to flourish over the site of the submerged forests. But that the sea, even though tenanted in these northern parts by a limestone-making fauna, was not so clear and well suited for the development of animal life during some of these submergences as it was farther south, seems to be proved by the paucity and dwarfed forms of the fossils, as well as by the admixture of clay in the stone.

Ireland presents a development of Carboniferous rocks, which on the whole follows tolerably closely that of the sister island. In the northern counties, the lowest members are evidently a prolongation of the type of the Scottish Calciferous Sandstones and Carboniferous Limestone. In the southern districts, however, a very distinct and peculiar facies of Lower Carboniferous rocks is to be observed. Between the Old Red Sandstone and the Carboniferous Limestone there occurs in the county of Cork an enormous mass (fully 5000 feet) of black and dark-grey shales, impure limestones, and grey and green grits, which have been so affected by slaty cleavage as to have assumed more or less perfectly the structure of true cleaved slates. To these rocks the name of Carboniferous Slate was given by Griffith. They contain numerous Carboniferous Limestone species of brachiopods, echinoderms, &c., as well as traces of land-plants in the grit bands. Great though their thickness is in Cork, they rapidly change their lithological character and diminish in mass, as they are traced away from that district. In the almost incredibly short space of 15 miles, the whole of the 5000 feet of Carboniferous Slate of Bantry Bay seems to have disappeared, and at Kenmare the Old Red Sandstone is followed immediately and conformably by the Limestone with its underlying shale. This rapid change is probably to be explained, as Jukes suggested, by a lateral passage of the slate into limestone ; the Carboniferous Slate being, in part at least, the equivalent of the Carboniferous Limestone. Between Bandon and Cork the Carboniferous Slate is conformably overlain by dark shales containing Coal-measure fossils, and believed to be true Coal-measures. Hence in the south of Ireland, the thick calcareous accumulations of the limestone series appear to be replaced by a corresponding depth of argillaceous sedimentary rocks.[1]

The Carboniferous Limestone covers a large part of Ireland. It attains a maximum in the west and south-west, where, according to Mr. Kinahan,[2] it consists in Limerick of the following subdivisions :—

		Feet.
Upper (Burren) Limestone	Bedded limestone	240
	Cherty zone	20
Upper (Calp) Limestone	Limestones and shales	1000
	Cherty zone	40
Lower Limestone	*Fenestella* limestone	1900
	Lower cherty zone	20
	Lower shaly limestones	280
Lower Limestone Shales		100
		3600

The chert (phtanite) bands which form such marked horizons among these limestones are counterparts of those found so abundantly in the Carboniferous Limestone of England and Scotland. Portions of the limestone have a dolomitic character, and sometimes are

[1] J. B. Jukes, *Memoirs Geol. Survey, Ireland*, Explanation of Sheets 194, 201, and 202, p. 18 ; Explanation of Sheets 187, 195, and 196, p. 35.

[2] 'Geology of Ireland,' p. 72.

oolitic. Great sheets of basalt and tuff, representing volcanic eruptions of contemporaneous date, are interpolated in the Carboniferous Limestone of Limerick (Fig. 332). As the limestone is traced northwards, it shows a similar change to that which takes place in the north of England, becoming more and more split up with sandstone, shale, and coal-seams.[1]

2. MILLSTONE GRIT.—This name is given to a group of sandstones and grits, with shales and clays, which runs persistently through the centre of the Carboniferous system from South Wales into the middle of Scotland. In South Wales it has a depth of 400 to 1000 feet; in the Bristol coal-field, of about 1200 feet. Traced northwards it is found to be intercalated with shales, fire-clays, and thin coals, and, like the lower members of the Carboniferous system, to swell out to enormous dimensions in the Pennine region. In North Staffordshire, according to Mr. Hull, it attains a thickness of 4000 feet, which in Lancashire increases to 5500 feet. These massive accumulations of sediment were deposited on the north side of a ridge of more ancient Palæozoic rocks, which, during all the earlier part of the Carboniferous period, seems to have extended across central England, and which was not submerged until part of the Coal-measures had been laid down. North of the area of maximum deposit, the Millstone Grit thins away to not more than 400 or 500 feet. It continues a comparatively insignificant formation in Scotland, attaining its greatest thickness in Lanarkshire and Stirlingshire, where it is known as the "Moor Rock." In Ayrshire it does not exist, unless its place be represented by a few beds of sandstone at the base of the Coal-measures.

The Millstone Grit is generally barren of fossils. When they occur, they are either plants, like those in the coal-bearing strata above, or marine organisms of Carboniferous Limestone species. In Lancashire and South Yorkshire, indeed, it contains a band of fossiliferous calcareous shale undistinguishable from some of those in the Yoredale group and Scaur limestone.

3. COAL-MEASURES.—This division of the Carboniferous system consists of numerous alternations of grey, white, yellow, sometimes reddish, sandstone, dark-grey and black shales, clay-ironstones, fire-clays, and coal-seams. In South Wales it attains a maximum depth of 4800 feet; in the Bristol coal-field, about 6500 feet, in North Staffordshire about 5000 feet, which in South Lancashire increases to 8000. These great masses of strata diminish as we trace them eastwards and northwards. In Derbyshire they are about 2500 feet thick, in Northumberland and Durham about 2000 feet, and about the same thickness in the Whitehaven coal-field. In Scotland they attain a maximum of over 2000 feet. Some of these remarkable variations in thickness take place within short distances, as we have seen to be also the case in regard to the Carboniferous Limestone series. Thus in the South Wales coal-field the Coal-measures, like the limestone, are thinnest towards the east and rapidly thicken westward. They are 1880 feet thick in Monmouthshire, and swell out to 3126 in the east of Glamorganshire and to 4753 feet in the west of the same county. Yet the direct distance within which this increase takes place is not more than 40 miles. There can be little doubt that the Carboniferous period was one of considerable terrestrial disturbance, some areas sinking, others remaining long stationary, and others undergoing upheaval. The occurrence of a marked unconformability in the Shropshire Coal-measures affords a striking proof of these movements.[2]

It must of course be borne in mind that except possibly in some parts of the Midlands the visible top of the Coal-measures is in Britain a denuded surface even when preserved under later formations, and that it is impossible to say how much of the strata originally deposited has been removed. Palæontological considerations, to be immediately adverted to, indicate that the closing part of the Carboniferous period is not now represented in Britain by fossiliferous strata. Towards the end of the

[1] Hull's 'Physical Geology and Geography of Ireland,' 2nd. edit. (1891), p. 49.
[2] W. Shone, *Q. J. G. S.* lvii. (1901), p. 86.

Carboniferous period, possibly also within early Permian time, the terrestrial disturbances increased so much that the Carboniferous system was in many, if not most, districts of Britain upheaved so as to be exposed to denudation. In some areas the denudation was so great that the Permian rocks, as in the case of the Magnesian Limestone of Durham, sweep across the denuded edges of the Coal-measures, Millstone grit, and even the higher parts of the Carboniferous Limestone.

The Coal-measures are susceptible of local subdivisions indicative of different and variable conditions of deposit. The following table shows the more important of these:—

Bristol and Somerset. (Feet.)	Glamorganshire.[1] (Feet.)	South Lancashire. (Feet.)	Central Scotland. (Feet.)
Upper series, comprising the Radstock series of sandstones and shales, with 8 seams of coal underlain by the Farrington series, with a group of red shales having a distinctive flora 2000	Upper series: sandstones, shales, &c., with 7 workable coal-seams, more than . . . 1300	Upper series: shales, red sandstones, Spirorbis limestone, ironstone, and thin coal-seams 1600 to 2000	Upper red sandstones and clays, with Spirorbis Limestone, probably equivalent to the Middle Coal-measures of England; in Fife upwards of . 900
Middle series, chiefly sandstones with Pennant grit (970 feet) . . . 2000	Pennant Grit: hard, thick-bedded sandstones, and 3 to 7 workable coal-seams . . . 1836	Middle series: sandstones, shales, clays, and thick coal-seams. The chief repository of coal 3000 to 4000	Coal-measures: sandstones, shales, fire-clays, with bands of black-band ironstone, and numerous seams of coal, probably representing the Lower Coal-measures of England. Thickness in Lanarkshire upwards of . 2000
Lower series, consisting of an upper group (Kingswood, &c.) and a lower group (Bristol, Vobster), of sandstones, shales, and coals . 2500	Lower series: shales, ironstones, and 12 to 25 workable coal-seams . . . 1670	Lower or Gannister series: flagstones, shales, and thin coals . 1400 to 2000	
Millstone Grit.	Millstone Grit.	Millstone Grit.	Moor Rock, or Millstone Grit.

The Coal-measures of Britain are marked by evidences of a mingling of lagoon and marine conditions. The numerous coal-seams with their underclays indicate the sites of wide tracts of swampy terrestrial vegetation. The intercalation of layers of shale and ironstone containing what were probably fresh-water or at least brackish water mollusks points to the complete or partial exclusion of the sea from these tracts, while the frequent interposition of bands containing undoubted marine shells shows that the sea could never have been far distant, but from time to time, during the slow subsidence of the region, spread over the submerged jungles. Hence the remarkable alternation of terrestrial or lagoon surfaces with the bottoms of shallow seas.

1. *The Lower Series.*—The Lower Coal-measures have furnished an abundant flora, in which the most common species are *Neuropteris heterophylla*, *Alethopteris lonchitica*, *A. decurrens*, *Sphenopteris obtusiloba*, *Lepidodendron ophiurus*, *Calamites Suckowii* and *C. ramosus*. *Sigillaria*, though represented by a number of species, is not common. Large tree-ferns make their appearance in rare stems of *Megaphyton frondosum* and *M. approximatum*.[2] Upwards of 70 species of marine fossils have been obtained from this group, the most distinctive being *Aviculopecten papyraceus*, *Gastrioceras* (*Goniatites*) *carbonarium*, *Posidoniella lævis*, and *P. minor*. In Scotland occasional bands of marine fossils occur even near the top of the Coal-measures which are believed to be the equivalents of the Lower series of England. Thus in Fife a shale forming the roof of a thin coal at the top of the series contains *Lingula*, *Orbiculoidea*, *Productus semireticulatus*, *Aclisina* (*Murchisonia*) *striatula*, *Bellerophon Ureii*, *Orthoceras*, and *Discites*.[3]

2. *The Middle Series* is distinguished by its much richer flora. While it includes the

[1] H. K. Jordan, Address to *South Wales Inst. Engin.* May 1898. "Memoir of Geological Survey on South Wales Coal-field."

[2] R. Kidston, *op. supra cit.* p. 225.

[3] J. W. Kirkby, *Q. J. G. S.* xliv. p. 747.

more frequent species found in the Lower series, it contains many additional forms peculiar to itself. The genus *Sphenopteris* here attains its chief development (*S. grandifrons, S. Sauveuri, S. Marratii, S. rotundifolia, S. mixta, S. coriacea, S. Jacquoti, S. flexuosa, S. trifoliolata*). The genera *Odontopteris* and *Neuropteris* are also represented by a larger number of species than has been observed on any other horizon, some of the species being found only here, together with a number of other genera of ferns. The Calamites are strongly represented, also *Sphenophyllum, Lepidodendron*, and *Sigillaria*, the last-named attaining here its maximum development and being represented by some species only found in this subdivision (*S. polyploca, S. elongata, S. deutschiana, S. Saulii, S. cordigera*). *Cordaites* abounds, its commonest species being here, as in the Lower series, *C. principalis*. The most distinctive mollusks of the English Middle Coal-measures are *Naiadites modiolaris* and *Anthracomya modiolaris*. These shells are not found in immediate association with the indubitably marine organisms, but on the contrary are mingled with a peculiar assemblage of fishes and reptiles, annelids and crustaceans, such as may be supposed to have inhabited brackish or fresh water, together with abundant remains of terrestrial vegetation.[1] Some of the more characteristic fishes are *Strepsodus sauroides* (Fig. 409 B), *Rhizodopsis sauroides, Megalichthys Hibberti, Cheirodus granulosus* (Fig. 409 A), *Janassa linguæformis, Sphenacanthus hybodoides* (Fig. 398), *Pleuracanthus lævissimus, Ctenoptychius apicalis*. Some species range from bottom to top of the Coal-measures—*e.g. Callopristodus pectinatus* and *Gyracanthus formosus*.[2]

3. *The Upper Series.*—This highest subdivision of the English Carboniferous system appears to be best developed in the Bristol and Somerset coal-field, but to be present also in the Midlands. It has lately been worked out in great detail by the Geological Survey in North Staffordshire, where it is capable of subdivision into four distinct groups of strata. At the base and passing continuously and conformably down into the Middle series comes (*a*) the Black-Band group (300 to 450 feet), consisting of grey sandstones, marls, and clays, with some thin coals, black-band ironstones, and seams of Spirorbis Limestone. (*b*) Etruria marls (800 to 1100 feet), red and purple marls and clays, with thin bands of green grit and seams of Spirorbis Limestone near bottom and top. (*c*) Newcastle-under-Lyme group (300 feet), grey sandstones and shales with four thin coals and an entomostracan limestone at the base. (*d*) Keele series (above 700 feet), red and purple sandstones and marls with thin black and grey limestones, grey sandstones, and an entomostracan shale at the base.[3] The flora of this series is characterised by the prominence of ferns of the genus *Pecopteris*, belonging to the *Cyatheites* group of Göppert (*P. arborescens, P. oreopteridea, P. Cistii, P. Bucklandii, P. pteroides, P. unita, P. crenulata, P. pinnatifida*, &c.), species which are not found on any other horizon. Another common fern is *Alethopteris Serlii*. There are likewise peculiar species of *Sphenopteris, Odontopteris*, and *Neuropteris*. Tree-ferns here attain their maximum development. *Calamites* appears to be dying out, likewise *Lepidodendron* and *Lepidophloios*, while *Sigillaria* shows great diminution, being represented by several species of which only one (*S. tesselata*) is common; of *Cordaites* two species are known. A specimen of *Walchia* has likewise been obtained near Birmingham.[4] The fauna of this series has its distinctive shell, *Anthracomya Phillipsii*, together with *Carbonicola Vinti*, the last British representative of this fresh-water genus. There occur also immense numbers of *Spirorbis* in the limestones, likewise various species of the ostracod genus *Carbonia* and some fishes (*Elonichthys, Megalichthys Hibberti, Cœlacanthus lepturus, Diplodus gibbosus, Ctenodus cristatus*).

[1] Wheelton Hind, *Q. J. G. S.* xlix. (1893), p. 259; *op. cit.* lv. (1899), p. 365; *Palæontog. Soc.* xlix. (1895).

[2] My friend Dr. Traquair has been kind enough to furnish me with information on this subject, which he has so carefully studied.

[3] W. Gibson, *Q. J. G. S.* lvii. (1901), p. 251.

[4] R. Kidston, *op. supra cit.* p. 229.

In North Staffordshire there appears to be no break in the conformable continuity of the Coal-measures. But in the adjoining county of Shropshire, at a distance of not more than 25 or 30 miles to the south-west, a strong unconformability (locally known as the "Symon Fault") has been detected between the Middle and Upper Coal-measures. The older strata have been thrown into folds, over the top of which the younger series has been laid down.[1] Other unconformabilities have been claimed in various districts both in England and Scotland. Discussion has arisen in recent years as to the value of these breaks and as to the relation of the Carboniferous to the Permian system. It has been proved that certain red rocks, which for many years had been regarded as Permian, are really continuous with undoubted Coal-measures and contain an unquestionable Carboniferous flora and fauna. It has likewise been demonstrated that the red colour of these strata is original, and consequently that the peculiar geographical conditions which produced the red sediments of Permian time had already set in during the Carboniferous period.[2] The Carboniferous flora persisted for a time under these altered conditions, but its remains become fewer as we ascend into the highest parts of the red series, while the fauna grows increasingly impoverished. The remarkable breccias which form so conspicuous a part of these red rocks in some areas of the Midlands, and have long been claimed as characteristically Permian, appear to form an integral part of the red series which graduates downward into the grey Coal-measures. If these breccias are retained as parts of the Permian system, it becomes clear that in this region no definite boundary-line can be drawn between Carboniferous and Permian deposits. Such gradations are of course perfectly natural, for there was no abrupt break in the continuity of the two periods. It may be an open question, for at least the present, whether or not any part of the red series of the Midlands below the base of the Trias should be separated from the Coal-measures and be regarded as Permian.

The breccias just referred to have much interest in the history of geological investigation, inasmuch as they were claimed by Ramsay in 1855 as proofs of glacial action in Permian time.[3] He pointed out their resemblance to moraine-stuff and boulder-clay, showing that the shapes of the stones recall those of ice-worn boulders and pebbles, and that in many cases they are distinctly striated. He believed that he could trace the origin of the contents of the breccias to the Silurian high grounds of North Wales, and he came to the conclusion that they had been transported by floating ice connected with glaciers, which existed among the hills of that region in the Permian period. Subsequent investigation has made it more probable that the materials of the breccias were not far transported, but may have been derived from a ridge of old Palaeozoic and pre-Cambrian rocks, the summits of which have been well-exposed by the denudation of the Triassic strata in Charnwood Forest and elsewhere. These deposits have been compared to the subaerial detritus accumulated by streams, as in the gravel fans at the foot of the hill-ranges in the drier parts of Western and Central Asia. But the character of the striation on the stones is strongly suggestive of ice-action, as is admitted

[1] T. C. Cantrill, *Q. J. G. S.* li. (1895), p. 542. W. J. Clarke, *op. cit.* lvii. (1901), p. 86.

[2] T. C. Cantrill, *op. cit.* li. (1895), p. 528. W. Gibson, *op. cit.* lvii. (1901), p. 215. It will be remembered that the peculiar red sediments of the Old Red Sandstone had, in like manner, made their appearance while an Upper Silurian fauna was still abundant.

[3] "On the occurrence of angular, sub-angular, polished and striated fragments and boulders in the Permian Breccia of Shropshire, Worcestershire, &c., and on the probable existence of Glaciers and Icebergs in the Permian Epoch," *Quart. Journ. Geol. Soc.* 1855, pp. 185-205. See also Mr. W. Wickham King, *Midland Naturalist*, xvi. (1893), p. 25; *Q. J. G. S.* lv. (1899), p. 97. R. D. Oldham, *op. cit.* l. (1894), p. 463. While the breccias in question are intercalated among strata continuous with undoubted Coal-measures, no trace of any glaciated surface of older rock has been found associated with them, and they become coarser towards the south-east and east, that is, away from the north-western source attributed to them by Ramsay. *Postea*, p. 1070.

even by those who do not wholly accept Ramsay's explanation. Since his day observations have multiplied in India, Australia, and South Africa, which considerably strengthen his inferences, and make it probable that in late Carboniferous or Permo-Carboniferous times a rigorous climate did really extend for a time over a large part of the southern hemisphere. The evidence from these countries will be stated in later parts of this section of the present volume (pp. 1057-1060).

On the Continent of Europe the Carboniferous system occupies many detached areas or basins—the result partly of original deposition, partly of denudation, and partly of the spread and overlap of more recent formations. There can be little doubt that the English Carboniferous Limestone once extended continuously eastward across the north of France, along the base of the Ardennes, through Belgium, and across the present valley of the Rhine into Westphalia. From the western headlands of Ireland this calcareous formation can thus be traced eastward for a distance of 750 English miles into the heart of Europe. It then begins to pass into a series of shales and sandstones, which, as already remarked, represent proximity to shore, like the similar strata in the north of England and Scotland. In Silesia, and still much farther eastwards, in central and southern Russia, representatives of the Carboniferous Limestone or Culm appear, but interstratified, as in Scotland, with coal-bearing strata. Traces of the same blending of marine and terrestrial conditions are found also in the north of Spain. But over central France, and eastwards through Bohemia and Moravia into the region of the Carpathians, the Coal-measures rest directly upon older Palæozoic groups, most commonly upon gneiss and other crystalline rocks. These tracts had no doubt remained above water during the time of the Carboniferous Limestone, but were gradually depressed during that of the Coal-measures.

The Carboniferous system of the European continent has been grouped by some geologists in three major divisions: 1st, the Lower (Culm, Dinantian), comprising all the Lower Carboniferous rocks up to the Millstone Grit; 2nd, the Middle (Westphalian where of the lagoon type; Moscovian where, as in Russia, of the marine type), embracing the Millstone Grit and Coal-measures up to the top of the Middle series of England; 3rd, the Upper (Stephanian, from St. Etienne, where the lagoon type is well developed; Gshelian or Uralian, where marine), including the highest part of the English Coal-measures (Radstock group).

France and Belgium.—In Belgium and the north of France the British type of the Carboniferous system is well developed.[1] It comprises the following subdivisions:—

Stephanian, Gshelian, Uralian.	Upper or zone of *Dictyopteris sub-Brongniarti.*	Zone of the gas-coals (*Charbons à gaz*, rich bituminous coals, with 28 to 40 per cent of volatile matter), containing 47 seams of coal. *Pecopteris nervosa, P. dentata, P. abbreviata, Alethopteris Serlii, Neuropteris rarinervis, Sphenopteris obtusiloba, S. neuropteroides, S. irregularis, S. macilenta, S. coralloides, S. herbacea, S. furcata, Calamites Suckowii, Annularia radiata, Sphenophyllum erosum, Sigillaria tessellata, S. mamillaris, S. rimosa, S. laticosta, Dorycordaites.*
		Zone of the "Charbons gras" (18 to 28 per cent volatile matter), soft caking coal (21 seams), well suited for making coke. *Sphenopteris nummularia, S. macilenta, S. chærophylloides, S. artemisifolia, S. herbacea, S. irregularis, Neuropteris gigantea, Alethopteris Serlii, A. valida, Calamites Suckowii, Sphenophyllum emarginatum, Sigillaria polyploca, S. rimosa, S. laticosta, Trigonocarpus Nöggerathii.*

[1] On the Carboniferous rocks of this area see De Koninck, 'Descriptions des Animaux Fossiles du Terrain Carbonifère de la Belgique' (1842-67). Gosselet's 'Esquisse,' already cited, and his 'L'Ardenne' (1888), chaps. xxii. and xxiii. Mourlon's 'Géologie.' Boulay, 'Terrain Houiller du Nord de la France et ses Végétaux fossiles,' Lille (1876). Dupont, *Bull. Soc. Roy. Belg.* (1883). R. Zeiller, *B. S. G. F.* xxii. (1895), p. 483. M. Bertrand, *Ann. Mines*, January 1893.

Westphalian, Moscovian.

Middle or zone of [illegible]

Zone of the "Charbons demi gras" (12 to 18 per cent [illegible] seams of coal, chiefly fitted for smiths and iron work [illegible] *pteris trifoliolata, S. coarctata, S. Hoeninghausi, S.* [illegible] *furcata, S. Schillingsii, S.* [illegible] [illegible] *furcatum, Alethopteris Davreuxi, Calamites Suckowii,* [illegible] *Sigillaria scutellata, S. elongata, S.* [illegible] *elliptica, S. Graeseri, S. tessellata, Pecopteris* [illegible]

Lower or zone of [illegible]

Zone of the "Charbons maigres." Lean or poor coal [illegible] only fit for making brick or burning lime (9 to 12 per cent [illegible] matter). *Sphenopteris Hoeninghausi, Pecopteris* [illegible] *Neuropteris Schlehani, Alethopteris lonchitica, Sphenopteris* [illegible] *folium, Annularia radiata, Sigillaria* [illegible] *Calamites Suckowii, Lepidodendron* [illegible] *Lepidophloios laricinus.*

Zone of *Productus carbonarius.* [illegible] *Dimorphoceras Gilbertsoni, Spirifer* [illegible] *Orthothetes [Streptorhynchus] crenistria,* [illegible] *inaequalis, Aviculopecten papyraceus,* [illegible]

Sandstones or quartzites passing into conglomerates (Millstone Grit), separated from the Carboniferous Limestone by carbonaceous shales with [illegible] coal-seams; chiefly developed towards the north-east [illegible]

Calcaire Carbonifère, Système Calcareux (Culm, Dinantian).

	[illegible]	[illegible]
Limestone of Visé. Often poor in fossils, distinguished by *Productus giganteus*	[illegible]	
Limestone of Lives (Napoleon marble of Belgium). Fossils numerous: *Productus undatus, P. semireticulatus, Spirifer glaber, S. duplicicostus, Rhynchonella (Hypothyris) pleurodon, Terebratula (Dielasma) sacculus*	[illegible]	
Limestone of Haut Banc, compact or oolitic in south part of Sambre basin, with *Productus sublaevis,* but in north part of that basin, as well as on the Meuse and in the Boulonnais, *Productus cora* replaces *P. sublaevis*	[illegible]	
Dolomite of Namur, well developed between Namur and Liege, and extending into the Boulonnais (Hure dolomite), alternating with grey limestone, containing *Chonetes* [illegible]	40	[illegible]
Limestone of Bachant, grey, bluish black, or black, with cherts (phtanites). *Productus cora* (and sometimes *P. giganteus*), *Spirifer tricornis, Dentalium* [illegible] *Euomphalus* [illegible] *Discites sulcatus, Orthoceras* [illegible]	[illegible]	[illegible]
Limestone of Waulsort, grey, often dolomitic; only seen [illegible] of the Meuse. *Spirifer cuspidatus,* [illegible]	[illegible]	[illegible]
Limestone of Anseremme, grey and blue veined limestone and dolomite. *Productus semireticulatus, Spirifer mosquensis, S. cuspidatus, Orthis resupinata*	[illegible]	[illegible]
Limestone of Dinant, only found in the Meuse area. *Productus semireticulatus, P. Flemingii, Pecten* [illegible]	[illegible]	
Limestone of Ecaussines ("petit granite"), crinoidal limestone. *Phillipsia gemmulifera, Productus semireticulatus, Spirifer mosquensis, Orthothetes crenistria, Orthis Michelini, Leptaena [Strophomena] rhomboidalis*	[illegible]	[illegible]
Limestones and shales of Avesnelles, black limestone (16 metres), resting upon argillaceous shales (10 metres). Among the numerous fossils of the limestone are *Productus Flemingii, P. Heberti, Chonetes variolaris, Rhynchonella (Hypothyris) pleurodon, Spirifer mosquensis, Straparollus (Euomphalus) aequalis, Pecten Eudoxina,* [illegible]	[illegible]	
	[illegible]	[illegible]

The base of these strata passes down conformably into the Devonian system, with

which, alike by palæontological and petrographical characters, it is closely linked. The Carboniferous rocks of the north of France and of Belgium have undergone considerable disturbance. A remarkable fault ("la grande faille" of this region) resulting from the rupture of an isoclinal syncline, and the consequent sliding of the inverted side over higher beds, runs from near Liège westwards into the Boulonnais, with a general but variable hade towards the south. On the southern side lie lower Devonian and Upper Silurian strata, below which the Carboniferous Limestone, and even Coal-measures are made to plunge. Bores and pits near Liège at the one end, and in the Boulonnais[1] at the other, have reached workable coal, after piercing the inverted Devonian rocks. By continuing the boring the same coals are found at lower levels in their normal positions. Besides this dominant dislocation many minor faults and plications have taken place in the Carboniferous area, some of the coal-seams being folded in zig-zag, so that at Mons a bed may be perforated six times in succession by the same vertical shaft, in a depth of 350 yards. At Charleroi a series of strata, which in their original horizontal position occupied a breadth of 8½ miles, have been compressed into rather less than half that space by being plicated into twenty-two zig-zag folds.

Southwards the plateau of crystalline rocks in central and southern France is dotted with more than 300 small Carboniferous basins which contain only portions of the Coal-measures. The most important of these basins are those of the Roannais and Beaujolais, St. Etienne, Autun, Commentry, Gard, and Brive. It would appear, however, that some of the surrounding slates are altered representatives of the lower parts of the Carboniferous system, for Carboniferous Limestone fossils have been found in them between Roanne and Lyons, and near Vichy.[2] Even as far south as Montpellier, beds of limestone full of *Productus giganteus* and other characteristic fossils are covered by a series of workable coals. Grand' Eury, from a consideration of the fossils, regards the coal-basins of the Roannais and lower part of the basin of the Loire, as belonging to the age of the "culm and upper greywacke," or of strata immediately underlying the true Coal-measures. But the numerous isolated coal-basins of the centre and south of France he refers to a much later age. He looks on these as containing the most complete development of the upper coal, properly so-called, enclosing a remarkably rich flora, which serves to fill up the palæontological gap between the Carboniferous and Permian periods.[3] Some of these small isolated coal-basins are remarkable for the extraordinary thickness of their coal-seams. In the most important of their number, that of the Loire (St. Etienne), 31 workable beds of coal occur, with a united thickness of 164 feet, in a total depth of 11,500 feet of strata. In the basin near Chalons and Autun, the main coal averages 40, but occasionally swells out to 130 feet, and the Coal-measures are covered, apparently conformably, by Permian rocks, from which a remarkable series of saurian remains has been obtained. In some of those small basins, like that of Brive, the Carboniferous strata consist in large part of breccias and coarse conglomeratic sandstones, which rest unconformably upon, and have been formed out of, the contorted gneisses and schists of the central plateau.[4] In other basins they have undergone intense compression and dislocation. A notable example of this complicated structure is furnished by the coal-field of the Gard on the east side

[1] For the Boulonnais, see Godwin-Austen, *Q. J. G. S.* ix. p. 231; xii. p. 38. Barrois, *Proc. Geol. Assoc.* vi. No. 1. Report of meeting at Boulogne, *B. S. G. F.*, sér. 3, viii. p. 483. Rigaux, *Mém. Soc. Sci. Boulogne*, vol. xiv. (1892); 'Notice Géol. sur le Bas Boulonnais,' Boulogne-sur-mer, 1892.

[2] Murchison, *Q. J. G. S.* vii. (1851), p. 13. Julien, *Comptes Rendus*, lxxviii. p. 74.

[3] Grand' Eury, 'Flore Carbonifère'; *Compt. rend. Congrès Géol. Internat.* Paris, 1900, p. 521. Bertrand, *Bull. Soc. Géol. France*, xvi. (1888), p. 517. Fayol, p. 968 *et seq.* Memoirs cited *ante*, p. 1051. Le Verrier, *Bull. Carte Géol. France*, No. 15, p. 34.

[4] G. Mouret, 'Bassin Houiller et Permien de Brive,' 1891.

of the ridge of crystalline rocks that form the Cevennes. The strata have there been not only ruptured but overturned, and traversed by thrust-planes on which portions of them have been pushed bodily forward.[1] In the north-west of France, representatives of the Carboniferous Limestone and the coal-bearing series above it are found. The Carboniferous Limestone is also well developed westward in the Cantabrian mountains in the north of Spain, where it likewise is surmounted by coal-bearing strata.[2]

North Germany.[3]—The Coal-measures extend in detached basins north-eastwards from Central France into Germany. One of the most important of these, the basin of Pfalz-Saarbrücken, lying unconformably on Devonian rocks, contains a mass of Coal-measures believed to reach a maximum thickness of not less than 20,000 feet, and divided into two groups:—

2. Upper or Ottweiler beds, from 6500 to 10,000 feet thick, consisting of red sandstones at the top, and of sandstones and shales, containing 20 feet of coal in various seams. *Pecopteris arborescens*, *Odontopteris obtusa*, *Carbonicola*, *Estheria*, *Leaia*; fish-remains.
1. Lower or main coal-bearing (Saarbrücken) beds, 5450 to 9000 feet thick, with 82 workable and 142 unworkable coal-seams, or in all between 350 and 400 feet of coal. Abundant plants of the middle and lower zone of the Upper Coal flora. The base of the Carboniferous system does not here reach the surface.

The Franco-Belgian Coal-field is prolonged across the Rhine into Westphalia. The Carboniferous Limestone here dwindles down as a calcareous formation, and assumes the "Culm" phase, passing up into the "flotzleerer Sandstein" or Millstone Grit—a group of sandstones, shales, and pebbly beds some 3000 feet thick, but without coal-seams. These barren measures are succeeded by the true Coal-measures, about 10,000 feet thick, with 90 workable seams of coal, having a united thickness of more than 250 feet.

Southern Germany, Bohemia.—Carboniferous rocks occur in many scattered areas across Germany southwards to the Alps and eastwards into Silesia, including representatives both of the lower or Culm phase and of the Coal-measures. The Culm rocks reappear in the Hartz, where they are traversed by metalliferous veins and enclose small patches of Coal-measures.[4] The same structure extends into Thuringia, the Fichtelgebirge, Saxony, and Bohemia, the series of shales, sandstones, greywackes, and conglomerates of the Culm yielding Carboniferous Limestone fossils, as well as *Megaphyton*, *Asterocalamites*, *Lepidodendron*, &c., and containing sometimes, as in Saxony, workable coals. The abundant fauna of the Carboniferous Limestone is reduced to a few mollusks (*Productus antiquus*, *P. latissimus*, *P. semireticulatus*, *Posidonomya Becheri*, *Goniatites* (*Glyphioceras*) *sphæricus*, *Orthoceras striatulum*, &c.). The *Posidonomya* particularly characterises certain dark shales known as "Posidonia schists." Of the plants, typical species are *Asterocalamites scrobiculatus* [*Calamites transitionis*], *Lepidodendron veltheimianum*, *Stigmaria ficoides*, *Sphenopteris distans*, *Cyclopteris tenuifolia*. This flora bears a strong resemblance to that of the Calciferous Sandstones of Scotland. True Coal-measures, however, also occur in these regions, though to a smaller extent than the lower parts of the system. One of the most extensive coal-fields is that of Silesia,[5] where the seams of coal are both numerous and valuable, one of them attaining a thickness of 50 feet. It is noteworthy that in

[1] M. Bertrand, *Compt. rend.* cxxx. 29th January 1900.

[2] Barrois, *B. S. G. F.* xiv. (1886), p. 660 (Finisterre); 'Recherches sur les Terrains anciens des Asturies,' p. 551. Zeiller (*Mem. Soc. Géol. Nord*, i. 1882) refers the Asturian plants to the Middle and Upper Coal-measures of France.

[3] Geinitz, 'Die Steinkohlen Deutschlands,' Munich, 1865. Von Dechen, 'Erläuterungen zur Geol. Karte der Rheinprov.' ii. (1884). C. E. Weiss, 'Fossile Flora der jüngsten Steinkohlen formation und des Rothliegenden im Saar-Rhein Gebiete,' 1869-72.

[4] H. Potonié on the Culm-Flora of the Harz, *Abhandl. Preuss. Geol. Landesanst.*, Neue Folge 36 (1901).

[5] D. Stur, *Abhandl. k. k. Geol. Reichsanst.* (1877).

the Coal-measures of eastern and southern Germany horizons of marine fossils occur like those so marked in the corresponding strata of Britain.

The coal-field of Pilsen in Bohemia occupies about 300 square miles. It consists mainly of sandstone, passing sometimes into conglomerate, and interstratified with shales and a few seams of coal which do not exceed a total thickness of 20 feet of coal. In its upper part is an important seam of shaly gas-coal (Plattel, or Brettelkohle), which, besides being valuable for economic purposes, has a high palæontological interest from Dr. Fritsch's discovery in it of a rich fauna of amphibians and fishes. The plants above and below this seam are ordinary typical Coal-measure forms,[1] but the animal remains present such close affinities to Permian types that the strata containing them may belong to the Permian system (pp. 1068, 1074). What are believed to be true Permian rocks in the Pilsen district seem to overlie the coals unconformably.

Alps, Italy.—The Carboniferous strata of the Alps have been already (p. 801) referred to in connection with the metamorphism of that region. They consist of conglomerates, sandstones, and dark carbonaceous shales, which in some places lie unconformably on the crystalline schists, with which elsewhere, owing to compression, they appear to be conformable or parallel. To the south-west of Mount Blanc the shales contain Coal-measure plants, *Pecopteris polymorpha* being the commonest form.[2] In other parts of the chain, the Carboniferous lenticles occur imbedded in or associated with a great series of reddish sandstones, conglomerates, and red or greenish shales or slates, which occasionally become quite crystalline, and cannot indeed be satisfactorily separated from what have been regarded as the primitive schists of the mountains. To these strata the name of "Verrucano" has been given. That they are partly, at least, of Carboniferous age is shown by the characteristic flora, amounting to upwards of 60 species, which the dark carbonaceous bands have yielded.[3] The plants have had their substance converted into a silvery sericitic mica. In Carinthia, through the labours of Stur, Stache, and others, Carboniferous formations have long been known to form part of the central and southern bands of the Alpine chain. They are especially developed in the Gail Thal, where they have yielded numerous marine fossils like those of the Carboniferous Limestone of Western Europe. They extend eastwards into Styria, and thence through the hilly ground of Illyria, Croatia, and Dalmatia. Shales, sandstones, conglomerates, and bands of *Fusulina*-limestone (with *Productus semireticulatus*, &c.), occur folded with the Trias on the western confines of Styria.[4]

Russia.—Over a vast region of the East of Europe Carboniferous limestones, sandstones, shales, and thin coal-seams are spread out almost horizontally. They unite the marine and terrestrial types of sedimentation so characteristic of the north of Britain. In the central provinces of Russia, the Moscow basin or coal-field of Tula, said to occupy an area of 13,000 square miles, lies conformably on the Old Red

[1] From the coal-field of Central Bohemia C. Feistmantel enumerated 278 species of plants, of which 137 were ferns (*Sphenopteris*, *Neuropteris*, *Odontopteris*, *Cyatheites*, *Alethopteris*, *Megaphyton*, &c.). *Archiv. Naturw. Landesdurchforsch. Böhmen*, v. No. 3, 1883. For the amphibian remains, see Fritsch's 'Fauna der Gaskohle.'

[2] E. Ritter, *Bull. Carte Géol. France*, No. 60 (1897), chap. vi. Duparc et Mrazec, *Mem. Soc. Phys. et Hist. Nat.* Geneva, xxxiii. (1898), p. 172.

[3] For an essay on these rocks, see L. Milch's 'Beiträge zur Kenntniss des Verrucano,' Leipzig, 1892. The metamorphism of Carboniferous and Permian rocks in the Alps of Savoy is described by P. Termier, *Bull. Carte Géol. France*, ii. (1891), p. 367. See also A. Favre, 'Géol. Savoie,' vol. iii. (1867), p. 192; A. Rothpletz, *Abhandl. Schweiz. Palæont. Gesellsch.* vi. (1879).

[4] A. Tommasi, *Boll. Soc. Geol. Ital.* viii. p. 564. C. F. Parona and L. Bozzi, *op. cit.* ix. pp. 56, 71. J. Teller, *Erläut. Geol. Kart.* (Pagerhof-Wind-Feistritz), Vienna, 1899, p. 41; *Id.* Prassberg. d. Sann. p. 34.

Sandstone or Devonian system, and contains limestones full of Carboniferous Limestone fossils, and a few poor seams of coal. In the south of the empire, the coal-field of the Donetz, covering an area of 11,000 square miles, contains 60 seams of coal, of which 44 having a united thickness of 114 feet, are workable. Again, on the flanks of the Ural Mountains, the Carboniferous Limestone series has been upturned and contains some workable coal-seams. It would appear, therefore, that this particular type of an upper marine and terrestrial strata of Carboniferous age occupies a vast expanse under later formations in the east of Europe. Since so much of the Russian development of the Carboniferous system consists of limestone, it is interesting to find that it contains so many of the familiar fossil species of the Carboniferous Limestone of Western Europe. Thus in the Ural region, according to Professor Tschernychew, the Carboniferous system may be divided into five zones, of which the lowest, a limestone containing *Productus giganteus*, *P. striatus*, *Chonetes papilionacea*, &c., may be paralleled with the Calcaire de Tournai and Visé in Belgium, and with the British Carboniferous series up to the top of the Yoredale group. The second, limestone with *Spirifer mosquensis*, may be regarded as corresponding to the non-productive strata of the west, with the Millstone Grit and Gannister group. The three upper zones, viz. those of (*a*) *Spirigera planosulcata*, *Spirifer striatus*, &c., (*b*) *Productus cora*, and (*c*) *Spirifer fasciger* and *Conocardium uralicum*, are probably equivalent to the Middle and Upper Coal-measures.[1] One of the most abundant and persistent organisms of the upper zones is the foraminifer *Fusulina*. The upper Carboniferous rocks on the west side of the Urals shade upwards into the base of the Permian system, and show a commingling of Carboniferous and Permian fossils.

Even as far north as **Spitzbergen** a characteristic Carboniferous flora has been obtained, comprising 26 species of plants, half of which are new, but among which we recognise such common forms as *Lepidendron Sternbergii* and *Cordaites borassifolius*.[2]

Africa.—The sea in which the brachiopods, corals, and crinoids of the Carboniferous Limestone lived extended across the Mediterranean basin into Africa. Species of *Productus*, *Athyris*, *Spirifer*, *Streptorhynchus*, *Orthis*, *Cyathophyllum*, &c., have been obtained in the western Sahara between Morocco and Timbuctoo.[3] Farther east, in Fezzan, between Ghat and Murzuk, what were believed to be Carboniferous Limestone fossils were obtained by Overweg as long ago as 1850. More recently other outcrops of Carboniferous rocks have been detected at various points of the interior. The latest discovery has been made in the inland region south-west of Tidikelt (Algeria), where a group of white limestones, grey and red marls and yellow lumachelles have furnished a number of corals (*Lophophyllum*, *Zaphrentis*, *Michelinia favosa*), crinoids (*Poteriocrinus*, *Rhodocrinus*), *Fenestella membranacea*, *Athyris lamellosa*, *Leptaena analoga*, *Productus semireticulatus*, *Spirifer*, *Pleurotomaria Yvanii*, *Orthoceras*—an assemblage that may be compared with that of the upper part of the Carboniferous Limestone of Belgium and England.[4] The red sandstones which extend into the peninsula of Sinai and thence into Palestine, have yielded stems of *Lepidodendron* and *Sigillaria*, and an intercalated limestone contains *Orthis Michelini* and *Orthothetes* [*Streptorhynchus*] *crenistria*.[5] A number of characteristic brachiopods of the Carboniferous Limestone have also been obtained from the hills in the Egyptian desert to the west of the Gulf of Suez, such as *Rhynchonella* (*Hypothyris*) *pleurodon*, *Productus semireticulatus*, *Spirifer striatus*.[6] In Southern Africa the existence of Carboniferous rocks has long been known.

[1] *Ann. Soc. Géol. Nord*, xvii. (1890), p. 201. Nikitin, *Mém. Com. Géol. Russ.* v. (1890), No. 5.

[2] Heer, *Flora Fossilis Arctica*, iv. (1877), p. 4.

[3] G. Stache, *Denksch. Acad. Wiss. Wien.* xlvi. (1893).

[4] G. Flamand, *Compt. rend.* cxxxiv. (1902), p. 1533.

[5] R. Tate, *Q. J. G. S.* xxvii. (1871), p. 404.

[6] J. Walther, *Z.D.G. G.* (1890), p. 419. E. Schellwien, *Z. D. G. G.* xlvi. (1894), p. 68.

Above certain slates and sandstones (Bokkeveldt) containing fossils with Devonian affinities come the quartzites of Cape Colony, enclosing *Lepidodendron* and other Carboniferous plants. These are unconformably overlain by the "Dwyka Conglomerate and the Ecca shales, mudstones and sandstones, some 4000 feet thick. The Ecca group has yielded a number of plants which are also found in the Karharbari and Damuda groups of India. It may be of Upper Carboniferous or Permian age. It is further alluded to on p. 1079.[1]

The Dwyka Conglomerate has given rise to much discussion. Some observers have regarded it as of volcanic origin, others have explained it to be a vast littoral accumulation, while the majority have adopted the view that it is a glacial accumulation, comparable with the Boulder-clay of Northern Europe and America. It is composed of stones varying from the smallest pebbles up to blocks weighing a ton or more, dispersed without definite arrangement in a dark grey or blue cement, which decomposes into a compact yellowish clay. Sheets of this material, 60 feet thick, alternate with horizontal stratified deposits, in which pebbles are sometimes abundant. The blocks in this conglomerate are covered with fine parallel striæ, like those of glacial origin. The older rocks on which the conglomerate rests unconformably have rounded, smoothed, striated and grooved surfaces precisely in the manner of *roches moutonnées* in a glacier valley, the markings mounting over the prominences in one general direction from south-east to north-west. The original source of some of the blocks has not been found in South Africa. It is believed that this remarkable accumulation has once covered the surface of the Transvaal, at least as far north as lat. 26° 40′ S. It extends southwards into Cape Colony, where it attains a thickness of more than 1200 feet.[2] Further allusion will be made to this subject after the similar deposits of Australia and India have been described. The age of the Dwyka conglomerate has not been definitely ascertained; it may be provisionally classed with the "Permo-Carboniferous" deposits of these countries.

Asia.—The Carboniferous system is extensively developed in Asia.[3] In China, where it covers an area of many thousand square miles, forming a succession of vast tablelands, it has been found by Richthofen to be composed of three stages: 1st, a massive brown bituminous limestone, which from its foraminifera (*Fusulina*, *Fusulinella*, *Lingulina*, *Endothyra*, *Valvulina*, *Climacammina*) is obviously the equivalent of the Carboniferous Limestone of Europe; 2nd, productive Coal-measures with both bituminous and anthracitic coals, and containing a characteristic Coal-measure flora, among which are numerous ferns of the genera *Sphenopteris*, *Palæopteris*, *Neuropteris*, *Callipteridium*, *Cyatheites*, &c., also species of *Calamites*, *Sphenophyllum*, *Lepidodendron* (including *L. Sternbergii*), *Stigmaria* (*S. ficoides*), *Cordaites*, and others; 3rd, Upper Carboniferous—sandstones, conglomerates, and thin limestones, containing marine fossils, among which are the cosmopolitan brachiopods mentioned on p. 1022.[4]

In India strata which may represent in part the Carboniferous system of Europe are developed in the western half of the Salt Range, where they consist of (1) a lower

[1] G. A. F. Molengraaf, *B. S. G. F.* 4me sér. i. (1901), p. 13.

[2] The observations of Sutherland, Dunn, Green, and other previous writers are cited by G. A. F. Molengraaf, *Trans. Geol. Soc. South Africa*, iv. (1898), p. 103 and *B. S. G. F.* i. (1901), p. 67. A paper by Messrs. Rogers and Schwarz advocates a glacial origin for the Prieska conglomerate of Orange River Colony, which is probably the same as the Dwyka rock, *Trans. Phil. Soc. South Africa* xi. (1900), p. 113. Since this passage was written information has been received of the discovery of a similar conglomerate, also believed to be of glacial origin, intercalated in the Table Mountain Sandstone. It differs in some respects from the Dwyka band and seems to lie on a different horizon. A. W. Rogers, *Trans. South African Phil. Soc.* xi. June 1902.

[3] See G. Fliegel, *Z. D. G. G.* l. (1898), p. 385.

[4] Richthofen, 'China,' vols. ii. and iv.

group of speckled sandstones resting unconformably on the older Palæozoic rocks, and containing at its base a remarkable boulder-bed with striated stones of the type of those in South Africa and Australia, and (2) a group of sandstones and highly fossiliferous limestones and marls (Productus beds), which have long been known for their remarkable admixture of Ammonites among organisms of characteristically Palæozoic type, such as *Athyris Roissyi*, *Spirifer striatus*, *Productus cora* and *P. semireticulatus*. The higher member of this group, a sandy dolomite not more than 100 feet thick, contains a rich fauna having a Permian facies, but together with the Palæozoic forms are the ammonites *Cyclolobus Oldhami*, *Arcestes antiquus*, *A. priscus*, *Xenodiscus carbonarius*, *X. plicatus*, and *Sageceras haueriamum*. In the Central Himalayas crinoidal limestones have been found in the Milam Pass containing some familiar Carboniferous Limestone species, and similar fossils have been met with in Cashmere. The great Gondwana system of the Indian peninsula, composed of a mass of strata probably in the main of fluviatile origin, appears to represent the upper Palæozoic and older and middle Mesozoic formations of other countries. It is divided into two sections, whereof the lower comprises three formations, which in ascending order are the Talchir, Damuda, and Panchet. Of these the Talchir may be paralleled with the Upper Carboniferous rocks of Europe and the Dwyka and Ecca groups of South Africa. The most remarkable feature in the Talchir group is the occurrence of blocks of all sizes up to masses 15 feet in diameter and 30 tons in weight, which have been dropped among the sandstones and the finest shales. In one instance the large boulders have been observed to show smoothed and striated surfaces, and the surface of the underlying limestone is found to be also polished, scratched and grooved. These features are believed by the geologists who have studied them to be only explicable by ice-action. Nor is this the only example of them in India. Reference has just been made to the boulder-bed of the Salt Range. Other instances have been noticed in the Spiti valley, Central Himalayas, in Simla, and in Cashmere.[1]

Australasia.—In Australia, important tracts of true Carboniferous rocks, with coal-seams, range down the eastern colonies, and are well developed in Queensland, where the government geologists have grouped a thick series of four or five formations under the name of Permo-Carboniferous. The oldest of these is termed (1) the Gympie series, which attains in its typical locality a thickness of 2000 feet, but sometimes reaches more than ten times that amount. It consists of various sandy argillaceous and calcareous rocks with some volcanic intercalations, and has yielded besides some plants (*Cordaites australis*, *Lepidodendron australe*), numerous marine fossils, among which are *Fenestella fossula*, *Protoretepora ampla*, *Spirifer vespertilio*, *Leptæna rhomboidalis*, and *Productus cora*. (2) The Star formation (1353 feet) consists of sandstones, conglomerates, shales, and thin limestones, in which, besides a mingling of plant remains (*Lepidodendron veltheimianum*, *L. australe*, *Calamites varians*) a marine fauna is found, including some characteristic Carboniferous Limestone genera and species, as *Actinocrinus*, *Phillipsia*, *Fenestella*, *Rhynchonella* (*Hypothyris*) *pleurodon*, *Reticularia Urei*, *Retzia radialis*, *Orthis resupinata*, *Leptæna rhomboidalis*, *Orthoceras*. The Brown River coal-field includes three formations, of which the lowest is (3) the Lower Bowen formation, which is made up chiefly of coarse volcanic agglomerate and amygdaloidal lava, with conglomerates and sandstones nearly 1000 feet in thickness. (4) The middle Bowen formation, composed of alternations of sandstones and shales, with two seams of coal and some conglomerates in the lower part, has furnished a large series of fossils, which include

[1] The glacial origin of the phenomena in question has been ably advocated by Dr. W. T. Blanford, 'Manual of Geology of India,' 1st edit. and in his Address to Geological Section of British Association, Montreal; and by H. F. Blanford, *Q. J. G. S.* xxxi. (1875), p. 519; W. Waagen, *Jahrb. Geol. Reichsanst.* xxxvii. (1887), p. 143; F. Noetling, *Neues. Jahrb.* 1896, ii. p. 61 (where a bibliography of the subject is given), and R. D. Oldham in 'Manual of Geology of India,' 2nd edit. 1893, chaps. vi. and vii.

Sphenopteris, *Glossopteris*, and many marine animals (*Stenopora*, *Fenestella fossula*, *Terebratula cymbæformis*, *Dielasma sacculus*, *Spirifer convolutus*, *S. trigonalis*, *Productus cora*, &c.). (5) The Upper Bowen formation, made up of 1000 feet or more of grey shales and greenish-grey, sometimes pebbly sandstones, with trees and a number of coal-seams, and containing *Phyllotheca australis*, *Sphenopteris lobifolia*, *S. flexuosa*, *S. crebra*, *Glossopteris browniana*, *G. linearis*, *Derbyia senilis*, *Productus brachythærus*, and *Goniatites*.[1]

In the Kimberley district of West Australia limestones 1000 to 1300 feet thick, with red marl, gypsum, and rocksalt, and covered by about 1500 feet of lacustrine or fluviatile sandstones, have yielded some familiar Carboniferous Limestone species (*Productus giganteus*, *P. semireticulatus*, *Rhynchonella* (*Hypothyris*) *pleurodon* and others).[2]

In New South Wales the Carboniferous formations are divisible into: 1st, Lower Carboniferous (or Upper Devonian)—sandstones, conglomerates, limestones, and shales, much disturbed by granite in some places, traversed by valuable auriferous quartz-reefs, and yielding plant-remains (*Lepidodendron australe*), *Spirifer disjunctus* and *Rhynchonella* (*Hypothyris*) *pleurodon*; 2nd, Upper or Permo-Carboniferous, including a series of coal-bearing strata, both below and above which are thick masses of calcareous conglomerates and sandstone abounding in marine fossils. The coal-seams are sometimes 30 feet thick, and among the plants associated with them are five species of *Glossopteris*, also *Gangamopteris* (several species), *Phyllotheca*, *Annularia*, *Vertebraria*, *Brachyphyllum*, and *Nöggerathiopsis*. The genus *Glossopteris* was formerly believed to be entirely Mesozoic, and its occurrence with true Carboniferous organisms was for a time denied. There can now be no doubt, however, that it appears among strata in which are found the widespread and characteristic Carboniferous Limestone forms *Lithostrotion basaltiforme*, *L. irregulare*, *Fenestella plebeia*, *Athyris Royssii*, *Orthis Michelini*, *O. resupinata*, *Productus aculeatus*, *P. cora*. *P. longispinus*, *P. punctatus*, *P. semireticulatus*, and many more.[3] Professor T. W. E. David, in summarising our knowledge of the coal-bearing rocks of New South Wales, gives a thickness of 10,000 feet to the Upper or Permo-Carboniferous series. The productive Coal-measures lie in the upper series, which is subdivided into six groups. In descending order these are (6) the Newcastle Coal-measures; (5) Dempsey beds; (4) Tomago (East Maitland) group; (3) Upper Marine group; (2) Greta Coal-measures; (1) Lower marine series. The Newcastle coal-seams are notable for their thickness, the lowest of them being from eight to fifteen feet, and another, near Jamberoo, twenty-five feet thick. An unconformability and strong break in the flora separate the upper division from the lower Carboniferous (or Upper Devonian).[4]

One of the most interesting features of the Permo-Carboniferous formations of Australia is to found in the occurrence among them of conglomerates like the South African Dwyka conglomerate and those of India, filled with well-striated blocks and resting upon

[1] Messrs. Jack and Etheridge, 'Geology and Palæontology of Queensland,' chaps. vi. xxii.

[2] E. T. Hardman, "Report on the Geology of the Kimberley District," Perth, 1885.

[3] See the papers by W. B. Clarke, R. Etheridge jun., De Koninck, and Wilkinson, cited on p. 980.

[4] Prof. David, *Trans. Austral. Assoc. Soc.* vol. ii. (1890), pp. 459-465; *Proc. Linn. Soc. N.S. Wales*, viii. (1893); *Journ. Roy. Soc. N.S. Wales*, xxx. (1896). O. Feistmantel, *Mem. Geol. Surv. N.S. Wales, Palæontology*, No. 3, 1890, p. 37. The Carboniferous and Permo-Carboniferous corals of New South Wales are described by E. Etheridge, jun., *op. cit.* No. 5, 1891. E. A. N. Arber, *Q. J. G. S.* lviii. (1902), p. 1. For information on the Australian Coal-fields, see papers by Walker, Robertson, and Cox, *Trans. Fed. Inst. Min. Eng.* ii. (1891), pp. 268, 321; iv. (1893), p. 83. For a detailed account of the Permo-Carboniferous rocks and fossils of Queensland, see R. L. Jack and E. Etheridge, jun., 'The Geology and Palæontology of Queensland,' 1892, chaps. vi.-xxii.

rounded and striated bosses of older rocks. These boulder-beds are well stratified and are associated with finely laminated shales, indicating deposition in water. They suggest that the stones were dropped into the fine silt that was gathering on the sea-floor. No marine fossils, however, have been found in the deposits, the only organisms being remains of land-plants (*Gangamopteris*). The striæ on the boulders and the rounding, polishing and grooving of the rocks underneath so exactly resemble those produced by glaciers, that since the phenomena were originally observed and described by Selwyn, as far back as 1859, they have been generally accepted as proof of the action, either of land-ice or of floating-ice. They extend over a wide region, from at least as far south as latitude 42° S. in Tasmania to the Bowen River Coal-field in Queensland, latitude 20° 30′ S., and from about long. 137° 30′ E to about 151° 30′ E. In Victoria probably several thousand square miles are covered with these glacial conglomerates, which, with their included sandstones, attain the enormous thickness of 3500 feet or more. The ice which furrowed the rocks and transported the boulders appears to have moved from the south, but the source of the erratics is not definitely known. The glaciated materials are not confined to one platform; at Bacchus Marsh, in Victoria, there are at least nine or ten distinct boulder-beds, separated from one another by thick deposits of sandstone and conglomerate; and in New South Wales the Greta Coal-measures, more than 230 feet thick, and containing from 20 to 40 feet in thickness of coal, are intercalated between the erratic-bearing horizon of the Lower Marine group and that of the Upper Marine group.[1]

The evidence now accumulated from South Africa, India, Cashmere and Australia seems to point to some general operation on a gigantic scale in the southern hemisphere at the close of the Carboniferous or in the Permian period, whereby boulder-beds were produced and limestones and rocks *in situ* were polished, striated and grooved. The assemblage of these peculiar features so exactly reduplicates the familiar phenomena of the Glacial Period, that it is hardly possible to resist the conclusion which has been reached by those who have studied the details on the ground, that it proves the occurrence of a former ice-age in late Palæozoic time which rivalled in its extent, and seems to have surpassed in the magnitude of its deposits, the glaciation of the northern hemisphere. From the fact that the boulder beds are intercalated among marine strata it is clear that, to some extent at least, the ice reached sea-level. We are still in ignorance, however, of the position of the high grounds from which the ice-sheets descended.[2]

In New Zealand rocks assigned to the Permo-Carboniferous period consist of a large mass of sandstones and shales, or slates and occasional limestones passing down into true limestones at the base, from which *Spirifer bisulcatus*, *S. glaber*, *Productus brachythærus*, &c., have been obtained. They are estimated to be from 7000 to 10,000 feet thick, and though they do not yield coal, they are geologically important from the large share they take in the structure of the great mountain-ranges, and from the

[1] Professor Edgeworth David, *Q. J. G. S.* lii. (1896), p. 289 (where an excellent account of the phenomena is given, also a bibliography of the writings of previous observers), Address to Section C. Australasian Assoc. Brisbane, 1895; *Journ. Proc. Roy. Soc. N. S. Wales*, xxxiii. (1900), p. 154.. Penck, *Zeitsch. Gesell. Erdkunde*, Berlin, xxxv. No. 4. (1900).

[2] The early paper by A. C. Ramsay, already cited (p. 1050), was the starting-point of inquiry into possible Palæozoic glacial periods, in regard to which a considerable mass of writing has since been published. Traces of such periods have been claimed for a succession of geological formations up into the pre-Cambrian series (Torridonian). Of those dealing with supposed Carboniferous glaciation reference may here be made to A. Julien, who has advocated the glacial origin of the coarse Carboniferous breccias of Central France, *Compt. rend.* cxvii. (1893), p. 255; and to Dr. E. Kalkowsky, who has described what he believes to be a glacial pebbly shale from the Carboniferous rocks of the Frankenwald, *Z. D. G. G.* xlv. (1893), p. 69.

occasional abundant development in them of contemporaneous igneous rocks, which are associated with metalliferous deposits.[1]

North America.—Rocks corresponding in geological position and the general aspect of their organic contents with the Carboniferous system of Europe are said to cover an area of more than 200,000 square miles in the United States and British North America.[2] The following table shows the subdivisions which have been established among them in the typical Appalachian region.

Upper Carboniferous.	Upper Coal-bearing or productive Measures (Monongahela River series, 200 to 400 feet), with six coal-seams (*Neuropteris hirsuta*, *N. flexuosa*, *Pecopteris arborescens*).[3]
	Barren Measures (Elk River or Conemaugh series, 300 to 800 feet), consisting of an upper group of shales and a lower group of sandstones, and including some variable coal-seams, ironstones, limestones. Some of the limestones contain *Productus longispinus*, *P. semireticulatus*, and species of *Spirifer*, *Athyris*, &c., while these marine organisms are sometimes, as in Scotland, found in the roof of a coal-seam.
	Lower Coal-bearing or productive Measures (Alleghany River series, 250 to 300 feet), containing a valuable series of coals among strata of sandstone, shale, fire-clay, and limestone.
	Pottsville Conglomerate series, hard white sandstones, often conglomeratic, with abundant trunks of *Lepidodendron* and *Sigillaria* (150 to 300 feet, but in West Virginia increasing to 700 and farther on to 1800 feet). These porous rocks are the repository of much salt water, as well as some oil and gas. In West Virginia coal is conspicuous in the middle and lower half of the series.
Lower Carboniferous.	Mauch Chunk series of red shales and sandstones (650 feet), lying on the Greenbrier limestone (200 to 250 feet, but in West Virginia 1000 feet or more).
	Pocono series of grey sandstones and conglomerates, extending from Pennsylvania across Maryland into West Virginia (400 to 450 feet).

South-westwards the Carboniferous system increases in thickness, and appears to attain in the State of Arkansas its maximum development on the American Continent, as shown in the subjoined table.[4]

Pennsylvanian.	Upper Coal-measures	Protean Beds	3500
		Productive Beds	1800
	Lower ,,	Barren Beds	18,480
	Millstone Grit		500
Mississippian.	Lower Carboniferous	Chester, St. Louis, and Warsaw groups (Boston group)	780
		Keokuk and Burlington groups	880
			25,940

[1] Hector's 'Handbook of New Zealand,' 1883, p. 35. F. W. Hutton, *Q. J. G. S.* 1885, p. 200. *Trans. New Zealand Inst.* xxxii. (1899), p. 159.

[2] A large body of literature has grown up regarding the Carboniferous formations of North America. The Canadian development is discussed in numerous Reports of the Geological Survey of Canada, and in Dawson's 'Acadian Geology'; that of the United States in numerous State Surveys, such as the Second Geological Survey of Pennsylvania, and in many papers scattered through the *American Journal of Science*, *Journal of Geology*, *Bulletin of the Geological Society of America*, *American Geologist* and other serials. The Bulletins, Annual Reports, and Monographs of the United States Geological Survey contain much valuable information on the subject. To some of these reference is made below.

[3] The fossil plants of the Carboniferous system of the United States have been well described and figured by L. Lesquereux, "Description of the Coal Flora in Pennsylvania and throughout the United States," in *Reports of Second Geological Survey of Pennsylvania*, vols. i.-iii., with Atlas of Plates, Harrisburg, 1880-84. See also D. White, 'Fossil Flora of the Lower Coal-measures of Missouri'; Monograph xxxvii. (1899), *U.S. G. S.*; *20th Ann. Rep. U.S. G. S.* 1900, pp. 749-918,—"The stratigraphic succession of the Fossil Floras of the Pottsville Formation in the Southern Anthracite Coal-field, Pennsylvania."

[4] J. C. Branner, *Amer. Journ. Sci.* ii. (1896), p. 235.

The Lower Carboniferous groups are mainly limestones, but contain here and there remains of the characteristic Carboniferous land vegetation. Crinoids of many forms abound in the limestones. A remarkable polyzoon, *Archimedes*, occurs in some of the bands. The brachiopods are chiefly represented by species of *Spirifer* and *Productus;* the lamellibranchs by *Myalina, Schizodus, Aviculopecten, Nucula, Pinna,* and others; the cephalopods by *Orthoceras, "Nautilus," Goniatites, Gyroceras,* &c. The European genus of trilobite, *Phillipsia,* occurs. Numerous teeth and fin-spines of selachian fishes give a further point of resemblance to the European Carboniferous Limestone. Some of the rippled rain-pitted beds contain amphibian footprints. Large deposits of gypsum occur in this stage in Nova Scotia.

In the Mississippi basin, where the Lower Carboniferous groups are most fully developed, they present the following subdivisions in descending order :—

Chester group.—Limestones, shales, and sandstones, sometimes 600 feet.
St. Louis group.—Limestones with shale, in places 250 feet.
Keokuk group.—Limestone with chert layers and nodules.
Burlington group.—Limestone, in places with chert and hornstone, 25 to 200 feet.
Kinderhook group.—Sandstones, shales, and thin limestones, 100 to 200 feet, resting on the Devonian black shale.

The Pottsville conglomerates and sandstones occupy a similar stratigraphical position to the Millstone Grit of Britain, like which they include in some districts seams of coal.

The Coal-measures vary from 100 feet in the interior continental area to more than 8000 feet in Nova Scotia. The plant remains include forms of *Lepidodendron, Sigillaria, Stigmaria, Calamites,* ferns, and coniferous leaves and fruits. The animal forms embrace in the marine bands species of *Spirifer, Productus, Bellerophon, "Nautilus,"* &c., some of which are world-wide species, found also in the Carboniferous Limestone (*Productus semireticulatus, P. punctatus, P. cora, Terebratula* (*Dielasma*) *hastata,* &c.).[1] Among the shales and carbonaceous beds numerous traces of the insect life have been obtained which was referred to on p. 1032. Spiders, scorpions, centipedes, limuloid crabs, and land-snails like the modern *Pupa* have also been met with, an especially rich harvest of organisms having been obtained from the erect tree-trunks of Nova Scotia (*ante*, p. 1033). The fish remains comprise teeth and ichthyodorulites of selachian genera (*Ctenacanthus, Edestus, Cladodus, Diplodus*), and a number of ganoids (*Eurylepis, Elonichthys, Cœlacanthus, Megalichthys, Rhizodus,* &c.). Several labyrinthodonts occur, besides the small amphibia from the Nova-Scotian trees; and true reptiles are represented by one saurian genus found in Nova Scotia, the *Eosaurus.*[2]

In the Western territories the Upper Carboniferous rocks consist of a massive group of limestones 2000 feet thick, resting on Lower Carboniferous strata ("Weber Quartzite" of King), estimated at 6000 to 10,000 feet, but with no coals.

The highest strata of the Carboniferous system in the United States are usually barren of coal. The characteristic Lepidodendra and Sigillariæ disappear and their place is taken by plants with Permian affinities (Pennsylvania, Ohio, W. Virginia), whilst in Illinois, Texas, and New Mexica, Permian reptiles occur in this part of the series. In these regions no definite upper limit to the system can be found, as it shades upwards into strata which may represent the Permian series of Europe.[3]

[1] J. P. Smith, "Marine Fossils from the Coal-measures of Arkansas," *Proc. Amer. Phil. Soc.* xxxv. (1897).

[2] On the classification of the Carboniferous system in Eastern Canada see H. M. Ami, *Trans. Nova Scot. Inst. Sci.* x. (1900), p. 162.

[3] See Report to the International Geological Congress, London, 1888, by J. J. Stevenson. Full details of the N. American Carboniferous system are given in Correlation Papers—Devonian and Carboniferous, by H. S. Williams, *Bull. U.S. Geol. Survey,* No. 80 (1891). See also C. S. Prosser, *Journ. Geol.* v. (1897), p. 148; vii. (1899), p. 342. C. R. Keyes, *Amer. Geol.* xxviii. (1901), p. 299.

South America. A large series of marine Upper Carboniferous fossils has been obtained from the district of the lower Amazonas below the mouths of the Rio Negro and the Madeira. Five fossiliferous groups are known, 1000 to 2000 feet thick, among which a blue amorphous limestone is remarkable for the excellent preservation of its silicified fossils. The list includes numerous species of *Productus*, *Spirifer*, *Athyris*, *Streptorhynchus*, *Aviculopecten*, *Schizodus*, *Pleurotomaria*, and *Bellerophon*, with species of *Phillipsia*, *Griffithides*, *Fusulina*, and other forms which, though specifically distinct, remind one of the general type of the marine Carboniferous fauna of Europe.[1]

Section v. Permian (Dyas).

§ 1. General Characters.

The Carboniferous rocks are overlain, sometimes conformably, but in Europe also unconformably, by a series of red sandstones, conglomerates, breccias, marls, and limestones. These used to be reckoned as the highest part of the Coal formation. In England they received the name of the "*New* Red Sandstone" in contradistinction to the "*Old* Red Sandstone" lying beneath the Carboniferous rocks. The term "Poikilitic" was formerly proposed for them, on account of their characteristic mottled appearance. Eventually they were divided into two systems, the lower being taken as the summit of the Palæozoic series of formations, and the upper as the basement of the Mesozoic. This arrangement, which is mainly founded on the difference between the organic remains of the two divisions, is generally adopted by geologists.[2]

Following the usual grouping, we remark that the portion of the red strata classed as Palæozoic has received the name of "Permian," from its wide development in the Russian province of Perm, where it was studied by Murchison, De Verneuil, and Keyserling. In Germany, where it exhibits a well-marked grouping into two great series of deposits, the name "Dyas," proposed by Geinitz, has on that account been to some extent adopted. In North America, where no good line of subdivision can be made at the top of the Carboniferous system, the term "Permo-Carboniferous" has been used to denote the transitional beds at the top of the Palæozoic series, and this name has been proposed for use also in Europe and in Australia.

In Europe two distinct types of the system can be made out. In one of these (Dyas) the rocks consist of two great divisions: (1) a lower series of red sandstones and conglomerates, and (2) an upper group of limestones and dolomites. In the other (Russian or Permian) the strata are of similar character, but are interstratified in such a way as to present no twofold petrographical subdivision.

Rocks. — The prevailing materials of the Permian series in Europe

[1] O. A. Derby, *Journ. Geol.* ii. (1894), p. 480.

[2] Some writers, however, still contend that the red rocks of Europe between the summit of the Carboniferous and base of the Jurassic system form really one great series, the break between them being merely local. See, for example, H. B. Woodward, *Geol. Mag.* 1874, p. 385; 'Geology of England and Wales,' 2nd edit. (1887), p. 207, and authorities cited by him.

are undoubtedly red sandstones, passing now into conglomerates and now into fine shales or "marls." In their coarsest forms, these detrital deposits consist of conglomerates and breccias, composed of fragments of different crystalline or older Palæozoic rocks (granite, diorite, gneiss, mica-schist, quartzite, greywacke, sandstone, &c.), that vary in size up to blocks a foot or more in diameter. Sometimes these stones are well rounded, but in many places they are only partially so, while, here and there, they are quite angular, and then constitute breccias. The pebbles are held together by a brick-red ferruginous, siliceous, sandy, or argillaceous cement. The sandstones are likewise characteristically brick-red in colour, generally with green or white layers and spots of decoloration. The "marls," showing still deeper shades of red, and passing occasionally into a kind of livid purple, are crumbling sandy clay-rocks, sometimes merging into more or less fissile shales. Of the argillaceous beds of the system the most remarkable are those of the Marl-slate or Kupferschiefer—a brown or black often distinctly bituminous shale, which in certain parts of Germany is charged with ores of copper. The limestone, so characteristic a feature in the "Dyas" development of the system, is a compact, well-bedded, somewhat earthy, and usually more or less dolomitic rock (Zechstein). It is the chief repository of the Permian invertebrates. With it are associated bands of dolomite, either crystalline and cavernous (Rauchwacke) or finely granular and crumbling (Asche); also bands of gypsum, anhydrite, and rock-salt. In certain localities (the Harz, Bohemia, Autun) seams of coal are intercalated among the rocks, and with these, as in the Coal-measures, are associated bituminous shales and nodular clay-ironstones. In Germany, France, the south-west of England, and the south-west of Scotland, the older part of the Permian system contains abundant contemporaneous masses of eruptive rock, among which occur diabase, melaphyre, andesite, tuffs, agglomerates, and various forms of quartz-porphyry.

Reference has already been made to the occurrence of breccias containing striated stones in the Midlands and west of England, and to the possibility that these rocks, which have long been accepted as of Permian age, may be more naturally placed near the top of the Carboniferous system. No satisfactory line can be drawn between the two systems in that region, and the breccias have accordingly been described together with other evidence of possible glacial action in Permo-Carboniferous times (pp. 1050, 1057-1060).

The Permian system in the greater part of Europe, from the prevalent red colour of its rocks, the association of dolomite, rock-salt, saliferous clays, gypsum, and anhydrite, and the remarkably impoverished and stunted aspect of its fauna, has evidently been deposited in isolated basins in which the water, cut off more or less completely from the sea, underwent concentration until chemical precipitation could take place. Looking back at the history of the Carboniferous rocks, we can understand how such a change in physical geography was brought about. The Carboniferous Limestone sea having been by upheaval excluded from the region, wide lagoons, wherein coal-forming vegetation accumulated,

occupied its site, and these, as the land slowly went down, crept over the old ridges that had for so many ages been prominent features. The downward subterranean movement was eventually varied by local elevations, and at last, after the close of the Carboniferous period, the Permian basins came to be formed. As a result of these disturbances, the Permian rocks overlap the Carboniferous, and even cover them in complete discordance, the denudation of the older formations having been, in some places, enormous before the Permian strata were laid down.[1]

In Southern Europe and thence eastwards, abundant evidence of open seas is supplied by limestone containing a rich pelagic fauna of foraminifera, gasteropods, orthoceratites, and early precursors of the ammonites.

LIFE. The conditions under which the Permian rocks of the greater part of Europe were deposited must have been eminently unfavourable to life. Accordingly we find that these rocks are on the whole singularly barren of organic remains. So great is the contrast between them and older formations, that instead of such rich faunas as those of the Silurian, Devonian, and Carboniferous systems, they have yielded only somewhere about 300 species of organisms.

The flora of the older Permian rocks presents many points of resemblance to the Carboniferous.[2] According to Grand' Eury upwards of 50 species of plants are common to the two floras. Among the forms which rise into the Permian rocks and disappear there, are *Calamites Suckowii*, *C. approximatus*, *Asterophyllites equisetiformis*, *A. rigidus*, *Pecopteris elegans*, *Odontopteris Schlotheimii*, *Sigillaria Brardii* (and others), *Stigmaria ficoides*, *Cordaites borassifolius*, &c. Others, which are mainly Permian, are yet found in the highest coal-beds of France, *e.g. Calamites gigas*, *Calamodendron striatum*, *Arthropitus ezonata*, *Tæniopteris abnormis*, *Walchia piniformis*, &c. But the Permian flora has some distinctive characters; such as the variety and quantity of the ferns united under the genus *Callipteris*, which do

[1] In some places, the whole of the Carboniferous system had been worn away down to the Carboniferous Limestone, upon which the Permian sandstones and conglomerates have been directly deposited. The discordance, however, sometimes disappears, and then the Carboniferous and Permian rocks shade into each other.

[2] See Göppert's 'Die Fossile Flora der Permischen Formation,' Cassel, 1864-65. E. Weiss, *Abhandl. Preuss. Geol. Landesanst.* iii. Heft 1. H. Potonié (Flora of the Thuringian Rothliegende), *op. cit.* Neue Folge, Heft 9; and "Die floristische Gliederung des Deutschen Carbon und Perm," *op. cit.* Heft 21. In this last paper, Potonié has recognised ten successive floras from the base of the Carboniferous system up into the Zechstein. Of these six are Carboniferous, viz.:—I. The Culm, with *Archæopteris dissecta* and abundant species of *Rhodea*. II. The Hultschiner Schichten of Upper Silesia, with *Adiantites oblongifolius* and *Sphenopteris elegans*. III. *Asterocalamites* extends thus far, and from here onward comes *Mariopteris muricata*; *Favularia*-zone. IV. Upper limit of *Neuropteris Schlehani*; many true Sphenopterids, *Palmatopteris furcata*, *Lonchopteris*, &c.; the richest flora in species. V. A flora similar generally to the last; from here onward, *Annularia stellata*. VI. Abundant Pecopterids; from here onward, *Sigillaria Brardii*. VII. Base of the Permian Rothliegendes, with *Callipteris* and *Walchia*. VIII. To this point come *Eucalamites* and *Calamitina*, but Carboniferous types are waning. IX. *Stylocalamites* ascends to this division, and from here onward come *Ullmannia Bronni* and *Baiera digitata*. X. Zechstein; hence onward *Voltzia* appears.

not occur in the Coal-measures, the appearance of *Glossopteris* and *Gangamopteris*,[1] the profusion of tree-ferns (*Psaronius*, of which 24 species are described by Göppert, *Protopteris, Caulopteris, Zygopteris, Asterochlæna, Selenochlæna, Tempskya, Medullosa*, &c.), of *Equisetites* (*Calamites major, C. decussatus, C. striatus, Arthropitus*), and of the conifers (*Walchia piniformis, W. filiciformis, W. hypnoides, Ulmannia Bronni, U. lycopodioides, Voltzia hexagona, Piceites, Araucarioxylon*). The most characteristic plants throughout the German Permian groups are *Odontopteris obtusiloba, Callipteris conferta, Calamites gigas*, and *Walchia piniformis*. The higher Russian subdivisions of the system, and also corresponding rocks in India, Australia, and other southern regions, contain what is called the *Glossopteris*-flora, with *G. indica, G. angustifolia, G. stricta, Gangamopteris major, G. cyclopteroides*. The last representatives of the ancient tribes of the Lepidodendra, Sigillarioids, and Calamites are found in the Permian system. Cycads now gained increased importance in this and succeeding geological periods. Among their Permian forms are the genera *Pterophyllum* and *Psygophyllum*. In extra-European Permian areas a marked commingling of Northern and Southern types of vegetation has been observed, forms of *Voltzia, Pterophyllum*, and *Glossopteris* being there prominent, together with species of *Lepidodendron* and *Sigillaria*.[2]

The impoverished fauna of the Permian rocks of Central Europe is found almost wholly in the limestones and brown shales, the red conglomerates and sandstones being, as a rule, devoid of organic contents. A few corals (*Polycœlia*) and polyzoa (*Fenestella, Phyllopora, Synocladia, Thamniscus, Acanthocladia*) occur in the limestones, the latter sometimes even in continuous masses like coral-reefs, as in the dolomite-reef of S.E. Thuringia. The last of the cystidean echinoderms died out in Permo-Carboniferous time. Among the brachiopods (Fig. 411 *a, b*), of which some 30 species are known, the most conspicuous are forms of *Productus, Camarophoria, Spirifer, Athyris, Strophalosia, Chonetes, Chonetina*, and *Aulosteges*. The long-lived families of the Productidæ, Orthidæ and Pentameridæ now appear for the last time. Lamellibranchs are not infrequent, characteristic genera being *Schizodus* (Fig. 411 *d*), *Allorisma, Solemya, Edmondia, Pleurophorus, Parallelodon, Aucella, Pseudomonotis, Bakevellia* (Fig. 411 *c*), and *Pecten* (*Streblopteria*), while the Russian brackish or freshwater strata contain *Palæomutela* and *Oligodon*. Among the few gasteropods, forms of *Naticopsis, Turbo, Murchisonia, Pleurotomaria, Cymatochiton*, and *Plagioglypta* have been recorded. An occasional *Temnocheilus, Orthoceras*, or *Cyrtoceras* represents the rich cephalopodan fauna of the Carboniferous Limestone. The last trilobites (*Phillipsia*) have been found in the Permian rocks of North America.

[1] These ferns, however, are found, as we have seen, in the Upper Carboniferous or Permo-Carboniferous rocks of Australia (p. 1059).

[2] Zeiller has recorded the association of *Gangamopteris* with *Lepidodendron* and *Lepidophloios* in the coal-beds of Rio Grande do Sul in Brazil (*B. S. G. F.* xxiii. (1895), p. 601). A Lepidodendron has been met with in Argentina among the *Glossopteris*-flora (*Rec. Geol. Surv. India*, xxix. Part ii. (1896), p. 58), and *Sigillaria* in similar company in South Africa (A. C. Seward, *Q. J. G. S.* liii. (1897), p. 315).

It is not, however, from the sites of the brackish inland seas of western and central Europe that we can obtain the best conception of the animal life of Permian time. If we pass southwards into the Alps and the Mediterranean basin, or eastwards into the Uralian region and thence into India, we find that while some of the European forms extend

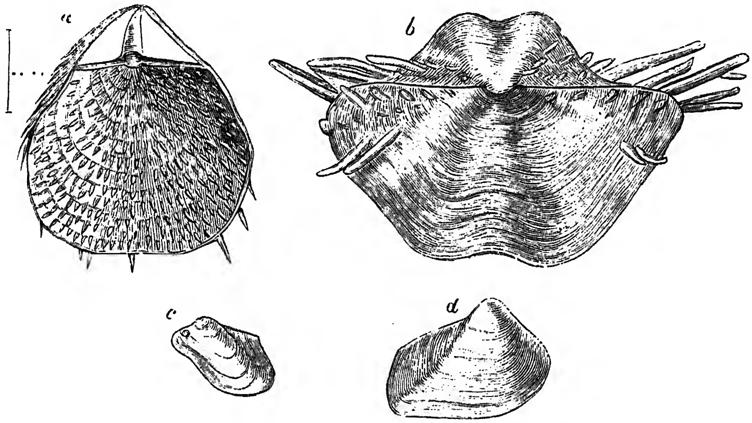

Fig. 411.—Permian Brachiopods and Mollusks.
a, Strophalosia Goldfussi, Münst. (enlarged); *b*, Productus horridus, Sow.; *c*, Bakevellia tumida, King; *d*, Schizodus Schlotheimii, Geinitz.

into these areas, they are accompanied by many hundreds of other species. One of the most remarkable features in this richer pelagic fauna is the great number of the cephalopods and the affinities which many of them present to the Ammonites so characteristic of Mesozoic time.[1] Among the Permian genera of this type are *Adrianites*, *Medlicottia*, *Popano-*

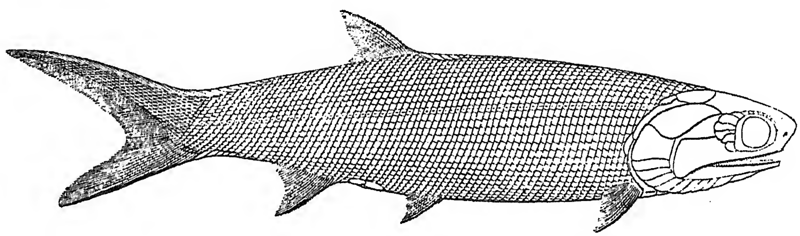

Fig. 412.—Palæoniscus macropomus, Ag. (½) Kupferschiefer.
From a restoration by Dr. Traquair.

ceras, *Stacheoceras*, *Thalassoceras*, and *Waagenoceras*. They are associated with many forms of *Orthoceras*, *Gyroceras*, and some which have been called *Nautilus* (though probably belonging to other genera)—a blending of

[1] On the structure and classification of the Permian Ammonites see E. Haug, *B. S. G. S.* xxii. (1894), p. 385.

Palaeozoic and Mesozoic types which is much less clearly shown in central and western Europe.

Fishes, which are proportionately better represented in the European Permian rocks than the invertebrates, chiefly occur in the marl slate or Kupferschiefer, the most common genera being *Palæoniscus* (Fig. 412), which is specially characteristic, *Platysomus* (Fig. 413), *Pygopterus*, *Acanthodes*, *Acrolepis*, and *Amblypterus*.

Amphibian life appears to have been abundant in Permian times, for some of the sandstones of the system are covered with footprints, assigned to the extinct order of Labyrinthodonts. Occasional skulls and other bones have been met with referable to *Archegosaurus*, *Branchiosaurus*, (*Protriton*, *Pleuronoura*), *Zygosaurus*, &c. The remains of comparatively few forms, however, had been found until the remarkable discoveries of Dr. Anton Fritsch in the basins of Pilsen and Rakowitz in Bohemia. The strata of these localities have been already (p. 1055) referred to as contain-

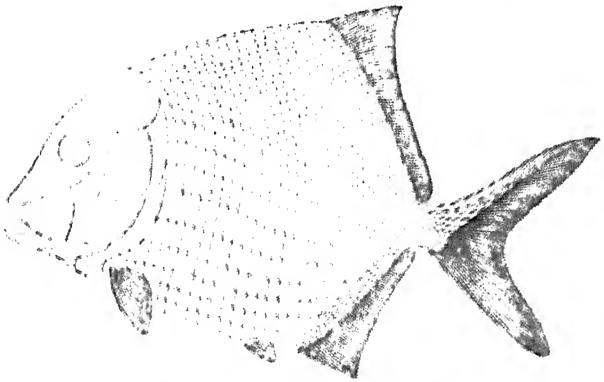

Fig. 413.—Platysomus striatus, Ag. (¼), Magnesian Limestone. Restored by Dr. Traquair.

ing an abundant and characteristic coal flora, yet with a fauna that is as decidedly like that of known Permian rocks. According, therefore, as we give preference to the plants or the animals, the strata may be ranked as Carboniferous or as Permian. Of the numerous Saxon and Bohemian species of amphibians, Professor Credner in Dresden and Dr. Fritsch in Prague have published elaborate descriptions. Among the genera are *Branchiosaurus*, a form resembling an earth salamander in possessing gills, and of which the largest specimen is only about $2\frac{1}{4}$ inches long, *Sparodus*, *Hylonomus*, *Dawsonia*, *Melanerpeton*, *Dolichosoma*, *Ophiderpeton*, *Macromerion*, *Urocordylus*, *Limnerpeton*, *Hyloplesion*, *Seeleya*, *Microbrachis*, *Diplospondylus*, *Nyrania*, and *Dendrerpeton*. Some of these forms are remarkably small. The adult Protritonidæ, for instance, were only from $2\frac{1}{2}$ to $6\frac{1}{2}$ inches long. Other types, however, attained a much larger size, *Palæosiren*, for instance, being estimated to have had a length of 15 feet.[1] From the

[1] A. Fritsch, 'Fauna der Gaskohle und der Kalksteine der Permformation Böhmens,' Prag. 1881. See also H. Credner on *Stegocephali* from the Rothliegendes of Dresden, *Z. D. G. G.* 1881-86. E. D. Cope, *Amer. Nat.* xviii. 1884.

corresponding strata of Autun in Central France, M. Gaudry also described some interesting forms—*Actinodon*, *Branchiosaurus*, *Euchirosaurus*, a larger and more highly organised type than any previously known from the Palæozoic rocks of France, but inferior to another subsequently found at Autun, which he named *Stereorhachis*, and which was distinguished by completely ossified vertebræ and other proofs of higher organisation that connect it with the Theriodonts of Russia and Southern Africa and with the Pelycosaurians of the United States.[1] Various other anomodont reptiles have been met with, referable to a number of genera (*Pareiasaurus*, &c.). Of still higher grade were other types, to which the names *Naosaurus*, *Clepsydrops*, *Proterosaurus*, and *Palæohatteria* (Rhynchocephalia) have been given. Some remarkably successful researches have in recent years been carried on by Professor Amalitzky among the Russian upper Permian formations, where he has disinterred fifteen or twenty skeletons of *Pareiasaurus*, some of which must have been four metres in length, four skeletons of reptiles resembling the Rhopalodonts, some bones belonging to Dicynodonts, many new genera of Theromorphs and probably of Deinosaurs, and lastly some stegocephalian skeletons (*Melanerpeton* and others).[2] Other traces of the terrestrial life of the time are furnished by the occasional occurrence of the remains of orthopterous insects,[3] scorpions, and millipedes.

No satisfactory scheme of subdivision of the Permian system has yet been devised capable of general application. In Europe, where the terrestrial and marine types of sedimentation are so well developed, it has been proposed to adopt a threefold arrangement. The lowest subdivision, which has been named Autunian (from Autun in France, where it displays the type with a terrestrial flora) or Artinskian (from Artinsk in Russia, where it presents the marine facies), includes Carboniferous genera and even species of plants and animals, but with a proportion of novel forms. The middle includes the Red Sandstones, which in Saxony and the north-west of England attain such development, and has been termed Saxonian. The upper comprises the English Magnesian Limetones and German Zechstein, and as it is typically displayed in Thuringia it has received the name of Thuringian.

§ 2. Local Development.

Britain.[4]—In England on a small scale, a representative is to be found of the two contrasted types of the European Permian system. On the east side of the island, from

[1] Gaudry, *B. S. G. F.* vii. (3 sér.) p. 62; ix. p. 17; xiii. p. 44; xiv. pp. 430, 444. 'Les Enchaînements du Monde Animal,' 1883; *Arch. Mus. Nat. Paris*, x. (1887).

[2] *Compt. rend.* March 1901; Seeley, *Phil. Trans.* clxxxv. (1894), p. 663.

[3] E. Geinitz, *Neues Jahrb.* 1873, p. 691; 1875, p. 1; *Nov. Act. Leop. Carol.* xli. 2 (1880).

[4] Sedgwick, *Trans. Geol. Soc.* (2) iii. (1835) p. 37; iv. 383. De la Beche, 'Geology of Cornwall, Devon,' &c. p. 193. Murchison, 'Siluria,' p. 308. W. King, 'Monograph of the Permian Fossils,' *Palæontog. Soc.* 1850. Hull, 'Triassic and Permian Rocks of Midland Counties of England,' in *Mem. Geol. Surv.* 1869; *Q. J. G. S.* xxv. 171; xxix. p. 402; xlviii. p. 60. Ramsay, *op. cit.* xxvii. p. 241. Kirkby, *op. cit.* xiii. xvi. xvii. xx. E. Wilson,

the coast of Northumberland southwards to the plains of the Trent, a true "Dyas" development is exhibited, the Magnesian Limestone and Marl Slate forming the main feature of the system; on the west side of the Pennine chain, however, the true Permian or Russian facies is presented. The system is in this country most nearly complete in the north-western and south-western counties of England. Arranged in tabular form the rocks of the western and eastern areas may be grouped as follows:—

	W. of England.	E. of England.
Red sandstones, clays, and gypsum	600 ft.	50–100 ft.
Magnesian Limestone, Marl slate	10–30 ,,	600 ,,
Lower red and variegated sandstone, reddish brown and purple sandstones and marls, with calcareous conglomerates and breccias	3000 ,,	100–250 ,,

Lower Sandstone.—This subdivision attains its greatest development in the vale of the Eden, where it consists of brick-red sandstones, with some beds of calcareous breccia, locally known as "brockram," derived principally from the waste of the Carboniferous Limestone. These red rocks extend across the Solway into the valleys of the Nith and Annan in the South of Scotland, where they lie unconformably on the Lower Silurian rocks, from which their breccias have generally been derived, though near Dumfries they contain some "brockram." The breccias have evidently accumulated in small lakes or narrow fjords. In the basin of the Nith, and also in Ayrshire, numerous small volcanic vents and sheets of diabase, picrite, olivine-basalt, andesite and tuff are associated with the red sandstones, marking a volcanic district of Permian age. The vents rise through Coal-measures, as well as more ancient rocks. Similar vents in Fifeshire, also piercing Coal-measures, have been referred to the same volcanic period. Of these vents no fewer than eighty have been observed in a space 12 miles long by 6 or 8 broad between St. Andrews and Largo. In Devonshire similar rocks mark the outpouring of lavas in the early part of the Permian period.[1] But these volcanic phenomena were on a feeble scale. They are interesting as marking the close of the long continuance of volcanic activity during Palæozoic time. Neither in Britain nor, save at one or two places on the Continent, has evidence been found of renewed eruptions during the long lapse of the Mesozoic ages.

In Central England, Staffordshire, the districts of the Clent and Abberley Hills and the lower basin of the River Severn, the rocks hitherto classed as Permian have been subdivided into three groups: 1st, Lower Sandstones and marls, 850 feet; 2nd, Breccia and conglomerate group, averaging perhaps 200 feet in thickness, with bands of calcareous conglomerate and the remarkable "trappoid" breccia which Ramsay adduced as evidence of glacial action (p. 1050); 3rd, Upper Sandstones and marls, 300 feet. The lower of these groups has been shown from its fossil contents to be really a part of the Upper Coal-measures, while the uppermost has much affinity with the Trias.[2] There appears to be no doubt that there is a practically unbroken series of red strata 1500 feet thick extending downwards into unquestionable Coal-measures and upwards into

op. cit. xxxii. p. 533. D. C. Davies, *op. cit.* xxxiii. p. 10. H. T. Brown, *op. cit.* xlv. p. 1. H. B. Woodward, *Geol. Mag.* 1874, p. 385; 'Geology of England and Wales,' p. 210. T. V. Holmes, *Q. J. G. S.* xxxvii. p. 286. W. T. Aveline and H. H. Howell in various *Memoirs Geol. Surv.* T. G. Bonney, *Midland Naturalist*, xv. (1892). W. W. King, *op. cit.* xvi. (1893), p. 25; *Q. J. G. S.* lv. (1899), p. 97. R. D. Oldham, *op. cit.* l. (1894), p. 463.

[1] A. G., *Geol. Mag.* (1866), p. 243; *Q. J. G. S.* (1892), Presid. Address, p. 147, and 'Ancient Volcanoes of Great Britain,' vol. ii. The Fife volcanic vents have been described by me in detail in the *Geol. Surv. Memoir* on Eastern Fife, 1902, chaps. xvii.-xx.

[2] T. C. Cantrill, *Q. J. G. S.* li. (1895), p. 528. W. Wickham King, *op. cit.* lv. (1899), p. 97.

the Trias. How much of this mass of sediments should be called Permian, and where the lines of separation are to be drawn, is still undecided. It will thus be seen that the remarkable breccias above referred to come into this debatable ground. They have generally been called Permian, but as the series of strata in which they lie passes down conformably into the Coal-measures, they may be claimed as Carboniferous, there being no decisive palæontological evidence to fix their stratigraphical horizon.

Like red deposits in general, the Lower Permian strata are almost barren of organic remains. Such as occur are indicative chiefly of terrestrial surfaces. Plant remains occasionally appear, such as *Ullmannia*, *Lepidodendron*, *Calamites*, *Sternbergia*, *Dadoxylon*, and fragments of coniferous wood. The cranium of a labyrinthodont (*Dasyceps*) has been obtained from the Lower Permian rocks at Kenilworth. Footprints, referred to members of the same extinct order, have been observed abundantly on the surfaces of the sandstones of Dumfriesshire, and also in the vale of the Eden.

Magnesian Limestone Group.—This subdivision is the chief repository of fossils in the Permian system of England. Its strata are not red, but consist of a lower zone of hard brown shale with occasional thin limestone bands (Marl Slate) and an upper thick mass of dolomite (Magnesian Limestone). The latter is the chief feature in the Dyas development of the system in the east of England. Corresponding with the Zechstein of Germany, as the Marl Slate does with the Kupferschiefer, it is a very variable rock in lithological characters, being sometimes dull, earthy, fine-grained, and fossiliferous, in other places quite crystalline, and composed of globular, reniform, botryoidal, or irregular concretions of crystalline and frequently internally radiating dolomite. It is divisible in Durham into three sections—1st, Lower compact limestone, about 200 feet thick; 2nd, Middle fossiliferous and brecciform limestone, 150 feet; 3rd, Upper yellow concretionary and botryoidal limestone, 250 feet. The Magnesian Limestone runs as a thick persistent zone down the east of England.[1] In southern Yorkshire it is split up by a central zone of marls and sandstones with gypsum.[2] It is represented on the Lancashire, Cheshire, and Cumberland (Penrith) side by bright red and variegated sandstones covered by a thin group of red marls, with numerous thin courses of limestone, containing *Schizodus*, *Bakevellia* and other characteristic fossils of the Magnesian Limestone. Murchison and Harkness have classed as Upper Permian certain red sandstones with thin partings of red shale, and an underlying band of red and green marls and gypsum. At Hilton Beck, Westmorland, a number of Permian plants have been found (*Sphenopteris Naumanni*, *S. dichotoma*, *Alethopteris Goepperti*, *Ulmannia selaginoides*, *U. Bronni*, &c.), and there occur also thin coal-seams in the same series of strata.

The Magnesian Limestone group of the north of England has yielded about 150 species belonging to some 70 genera of fossils—a singularly poor fauna when contrasted with that of the Carboniferous system below. The brachiopods include *Productus horridus*, *Spirifer alatus*, *Camarophoria humbletonensis*, *C. Schlotheimii*, *Strophalosia Goldfussi*, *Lingula Credneri*, and *Terebratula* (*Dielasma*) *elongata*. Of the lamellibranchs *Schizodus Schlotheimii*, *Bakevellia tumida*, *B. antiqua*, *B. ceratophaga*, *Mytilus squamosus*, and *Parallelodon striatus* are characteristic. The univalves are represented by 10 or more genera, including *Pleurotomaria* and *Turbo* as common forms. Nine genera of fishes have been obtained chiefly in the Marl Slate, of which *Palæoniscus* and *Platysomus* are the chief. These small ganoids are closely related to some which haunted the lagoons of the Carboniferous period. Some reptilian remains have been obtained from the Marl Slate, particularly *Proterosaurus Speneri* and *P. Huxleyi*, while the amphibian *Lepidotosaurus Duffii* has been found in the Magnesian Limestone.

[1] In a boring at Whitehouse, Norton, in the Tees district, the limestone was found to be only 299 feet thick—the thinnest development of it yet found in Durham.

[2] Some borings made in the Hartlepool district a few years ago showed the limestone to be there interleaved with anhydrite, and to be overlain with more than 250 feet of that deposit.

Fine sections are exposed on the south coast of Devonshire of coarse breccias and red sandstones, which have been assigned by some writers to the Trias, by others to the Permian series. They rest unconformably on Devonian strata, and have been derived from the degradation of these rocks. At many places in the interior to the west of Exeter bands of basic amygdaloidal lavas are intercalated in them, like the volcanic sheets above noticed as intercalated in the Permian sandstones of Scotland.[1] Owing to the apparent passage of these red strata upwards into others which graduate into the base of the Lias, and are undoubtedly Triassic, the whole series of red sediments has not unnaturally been regarded as referable to the Trias. The resemblance of the lower parts of this series to Permian rocks, however, coupled with the occurrence of volcanic bands in them, has been held to justify the separation of these lower breccias and sandstones from the rest as representatives of the Permian series of the Midlands.[2]

Germany,[3] **&c.** The "Dyas" type of the system attains a great development along the flank of the Harz Mountains, also in the Rhine province,[4] Thuringia, Saxony, Bavaria, and Bohemia. On the south side of the Harz it is grouped into the following subdivisions:

Zechstein Group.	Upper.	Anhydrite, gypsum, rock-salt, marl, dolomite, fetid shale, and limestone. The amorphous gypsum is the chief member of this group; the limestone is sometimes full of bitumen.
	Middle.	Crystalline granular (*Rauchwacke*) and fine powdery (*Asche*) dolomite (sometimes 150 feet thick, with gypsum at the bottom).
	Lower.	Zechstein-limestone, an argillaceous thin-bedded compact limestone 15 to 30 (sometimes even 90) feet thick. Kupferschiefer—a black bituminous shale not more than about 2 feet thick. Zechstein-conglomerate, and calcareous sandstone.
Rothliegendes Group.	Upper.	Red sandstones (*Kreuznach*), red shales (*Monzig*), with sheets of melaphyre, tuff, and quartz-porphyry conglomerate (*Sötern*).
	Lower.	Sandstones and conglomerates lying on black shales with poor coal seams (*Lebach*). Sandstones and shales, with some seams of coal resting on red and grey sandstones, with bands of impure limestone (*Cusel*).

The name "Rothliegendes," or rather "Rothtodtliegendes" (red-layer or red dead layer), was given by the miners because their ores disappeared in the red rocks below the copper-bearing Kupferschiefer. The coarse conglomerates have been referred by Ramsay to a glacial origin, like those of the Abberley Hills. They attain the enormous thickness of 6000 feet or more in Bavaria. One of the most interesting features of the formation is the evidence of the contemporaneous protrusion of great sheets of quartz-porphyry, granite-porphyry, porphyrite, and melaphyre, with abundant interstratifi-

[1] See B. Hobson, *Q. J. G. S.* xlviii. (1892), p. 496; 'Ancient Volcanoes of Great Britain,' vol. ii. and Teall, in *Summary of Progress of Geol. Surv.* 1899, p. 170.

[2] Hull, *Q. J. G. S.* xlviii. (1892), p. 60; A. Irving, *op. cit.* xliv. (1888) and xlviii. p. 68.

[3] H. B. Geinitz, "Dyas oder die Zechsteinformation und das Rothliegende,' 'Die animalischen Ueberreste der Dyas,' 1861-62, Suppl. 1880-82; 'Zur Dyas in Hessen,' *Festsch. Ver. f. Naturk.* Cassel, 1886. Geinitz and Gutbier, 'Die Versteinerungen des Zechsteingebirges,' &c. 1848-49. C. E. Weiss, 'Fossile Flora der jüngst. Steinkohlenf. und des Rothliegend.' &c. 1869-72. Much recent information will be found in the publications of the Geological Surveys of Prussia, Saxony, and Alsace-Lorraine. See, for example, E. W. Benecke and L. van Werveke, *Mitth. Geol. Landesanst. Elsass-Lothr.* iii. Part 2 (1890). A. von Reinach, *Abhandl. K. Preuss. Geol. Landesanst.* 1892, Heft 8. F. Frech, 'Lethæa Palæozoica,' ii. Lief. 3 and 4, 1901, 1902.

[4] For an account of the Permian development in this region, see especially H. von Dechen, 'Geolog. und Palaeont. Übersicht der Rheinprovinz und der Provinz Westfalen,' Bonn (1884), p. 291.

cations of various tuffs, not unfrequently enclosing organic remains.[1] In the district of the Saal these volcanic materials form almost the whole of the Lower Rothliegendes, and have been bored through to a depth of more than 1100 fathoms without their bottom being reached. The lowest or Landsberg-Löbejüner porphyry with large crystals has been computed to cover an area of 255 to 260 square kilometers, and to contain at least 80 cubic kilometers of material—a mass which may equal or exceed that of the eruption of Skaptar Jökul in 1786.[2] From the very nature of its component materials, the Rothliegendes is comparatively barren of fossils; a few ferns, calamites, and remains of coniferous trees are found in it, particularly in the lower part of the group, where they form thin seams of coal.

The plants, all of terrestrial growth, on the whole resemble generically the Carboniferous flora, but seem to be nearly all specifically distinct. They include forms of *Calamites* (*C. gigas*), *Asterophyllites*, and ferns of the genera *Callipteris* (*C. conferta*), *Sphenopteris*, *Alethopteris*, *Neuropteris*, *Odontopteris*, with well-preserved silicified stems of tree-ferns (*Psaronius*, *Tubicaulis*), *Cordaites*, and conifers. The conifer *Walchia* (*W. piniformis*) is specially characteristic. The mollusks have a fresh-water or lagoon facies (*Anthracosia*). There occur also species of ostracods (*Estheria*), while occasional traces of insects (*Blattina*, *Etoblattina*) have been met with. Fish remains occur sparingly (*Amblypterus*, *Palæoniscus*, *Acanthodes*, *Pleuracanthus*, *Ctenodus*), while, as already stated, labyrinthodonts have been found in the Dresden district in considerable number and variety.

The Zechstein group is characterised by a suite of fossils like those of the Magnesian Limestone group of England. The Kupferschiefer contains numerous fish (*Palæoniscus Freieslebeni*, *Platysomus gibbosus*, &c.) and remains of plants (coniferous leaves and fruits, *Ullmannia*, &c.). This deposit is believed to have been laid down in some enclosed sea basin, the waters of which, probably from the rise of mineral springs connected with some of the volcanic foci of the time, became so charged with metallic salts in solution as to be unfit for the continued existence of animal life. The dead fish, plants, &c., by their decay, gave rise to reduction and precipitation of these salts as sulphides, which thereupon enclosed and replaced the organic forms, and permeated the mud at the bottom. This old sea-floor is now the widely-extended band of copper-slate which has been so long and so extensively worked along the flanks of the Harz. After the formation of the Kupferschiefer the area must have been once more covered with clearer water, for the Zechstein Limestone contains a number of marine organisms, among which *Productus horridus*, *Spirifer alatus*, *Strophalosia Goldfussi*, *Terebratula* (*Dielasma*) *elongata*, *Camarophoria Schlotheimii*, *Schizodus obscurus*, and *Fenestella retiformis* are common. Renewed unfavourable conditions are indicated by the dolomite, gypsum, and rock-salt which succeed. Reasoning upon similar phenomena as developed in England, Ramsay connected them with the abundant labyrinthodont footprints and other evidences of shores and land, as well as with the small number and dwarfed forms of the shells in the Magnesian Limestone, and speculated on the occurrence of a long "continental period" in Europe, during one epoch of which a number of salt inland seas existed wherein the Permian rocks were accumulated. He compared these deposits to what may be supposed to be forming now in parts of the Caspian Sea.

Some of the deposits of the Zechstein in Germany have a great commercial value. The beds of rock-salt are among the thickest in the world. At Sperenberg, near Berlin, one has been pierced to a depth of nearly 4000 feet. Besides rock-salt and gypsum

[1] The petrography of these rocks (augite-porphyrite, basaltic, diabasic, and doleritic melaphyres) is described from the Upper Permian series of the Palatinate by A. Leppla, *Jahrb. Preuss. Geol. Landesanst.* xiv. (1893) p. 134.

[2] F. Beyschlag and K. von Fritsch, *Abhand. Preuss. Geol. Landesanst.*, Neue Folge, No. 10 (1900), p. 162.

there occur with these deposits thick masses of salts of potash (Carnallite), magnesia (Kieserite), and other salts.[1]

In Bohemia (pp. 1054, 1068) and Moravia, where the Permian system is extensively developed, it has been divided into three groups. (1) A lower set of conglomerates, sandstones, and shales, sometimes bituminous. These strata contain thin seams of copper ores, and abound here and there in remains of land plants and fishes. (2) A middle group of felspathic sandstones, conglomerates, and micaceous shales, with vast numbers of silicified tree-stems (*Araucarites*, *Psaronius*). (3) An upper group of red clays and sandstones, with bituminous shales. Eruptive rocks (melaphyre, porphyrite, &c.) are associated with the whole formation. The Zechstein is here absent. In place of the marine shells, crinoids, and corals so characteristic of that formation, the Bohemian Permian strata have yielded the remarkable series of amphibian remains already alluded to, together with abundant traces of the land of the period, such as remains of orthopterous insects, scorpions, millipedes, and a rich terrestrial flora (*Sphenopteris*, *Neuropteris*, *Odontopteris*, *Pecopteris*, *Alethopteris*, *Callipteris conferta*, *Schizopteris*, *Calamites*, *Asterophyllites*, *Sphenophyllum*, *Lepidodendron*, *Sigillaria*, *Walchia*, *Araucarites*, &c.).

Vosges. In this region the following succession of strata has been assigned to the Permian system:

4. Kohlbächel group of red arkoses, felspathic sandstones, shales, conglomerates, breccias, and dolomite, 500 to 600 feet, with interstratified sheets of porphyres and tuffs.
3. Variegated tuffs and marls of Meisenbuckel.
2. Dark shales, limestones, and dolomites of Heisenstein.
1. Arkose and shale (*Callipteris conferta*), with conglomerate (about 100 to 150 feet thick), containing blocks of porphyry, gneiss, quartz, &c., [illegible] of the crystalline schists on which they lie unconformably.

The existence of volcanic action during Permian time in this region is shown by the presence of interstratified basic lavas, and by the great quantity of fragments of quartz-porphyry in the conglomerates, which have been compared to volcanic agglomerates.[2]

France, &c. Permian rocks occur in many detached areas in France. In the central plateau they are found most fully developed, resting upon and passing down into the higher parts of the Carboniferous system. They have been carefully studied in the district of Autun, where the lower part of the Permian system is represented by a mass, 900 to 1000 metres thick, of alternations of sandstone and shale more or less rich in hydrocarbons, with thin bands of magnesian limestone. No marine fossils occur in these strata, even the magnesian limestone containing only fresh-water organisms. From the distribution of the fossils a threefold stratigraphical subdivision of the whole series has been made. 1st, A lower group at least 150 to 200 metres thick, lying conformably upon the Coal-measures, and containing numerous ferns (*Pecopteris*, abundant), *Sigillariæ*, *Cordaites*, a profusion of *Walchia*, large numbers of seeds or fruits, cyprids crowded in some layers of shale, a crustacean ([illegible]), a number of fishes (*Palæoniscus*, *Amblypterus*, *Acanthodes*, *Pleuracanthus*), and the amphibians and reptiles already referred to (*Actinodon*, *Euchirosaurus*, *Stereorhachis*). 2nd, A middle group about 300 metres thick, showing a cessation of the characteristically Carboniferous species of plants, and an increasing prominence of typically Per-

[1] F. Bischof, 'Die Steinsalzwerke bei Stassfurt,' Halle, 1875. C. Ochsenius, 'Die Bildung der Steinsalzlager,' Halle, 1877. Precht, 'Die Salzindustrie von Stassfurt,' 1885. Kloos, *Zeitsch. prakt. Geol.*, 1895, 1897.

[2] Benecke and Van Werveke, *Mitth. Geol. Landesanst. Elsass-Loth.* vol. iii. (1890), p. 45. Velain, *B. S. G. F.* ser. 3, xiii. Eck, 'Geogn. Karte d. Umg. von Lahr,' (1884), 'Geogn. Karte v. Schwartzwald' (1887). A bibliography for Alsace and Lorraine will be found in *Abh. Geol. Specialkart. v. Elsass-Lothringen*, vol. i. 1875, and vol. for 1887.

mian forms. Numerous species of *Pecopteris* still occur, but *Callipteris* makes its appearance (*C. conferta*, *C. gigantea*). *Walchia* (*W. piniformis*, *W. hypnoides*), *Calamites*, *Sphenophyllum*, *Calamodendron*, and fruits abound. The animal remains resemble those of the lower group, but with the addition of *Branchiosaurus*. 3rd, An upper group locally known as that of the "Boghead," from a workable band of bituminous shale or coal.[1] The thickness of this group is about 500 metres, the upper portion consisting of red sandstones without fossils. The flora is now markedly Permian. Pecopterid ferns are rare, and are specifically distinct from those in the group below. There is an abundance and variety of *Callipteris*, together with *Sigillaria*, abundant *Walchia* and *Asterophyllites*, *Piceites*, *Sphenophyllum*, *Carpolithus*, &c. The fauna is generally similar to that in the middle group, but less varied.[2]

In the extreme south of France, between Toulon and Cannes, Permian rocks reappear, and though occupying but a limited area, constitute some of the most picturesque features along the Mediterranean shores of the country. They consist of lower massive conglomerates, with intercalations of shale, containing *Walchia* and *Callipteris*, followed by shales, marls, red sandstones, and conglomerates. But their distinguishing feature is the enormous mass of volcanic materials associated with them. The lower conglomerates, besides their fragments of gneiss derived from the pre-Cambrian rocks of the district, contain abundant pieces of quartz-porphyry, of which rock also there are massive sheets, that rise up into the well-known group of hills forming the Esterel between Cannes and Fréjus. Besides these acid outbursts in the older part of the formation, sheets of melaphyre are found in the upper part, while dykes of nodular felsite, pitchstone, and melaphyre traverse the series.[3]

Farther east the terrestrial facies of the rocks is well displayed in Tuscany, where the shales of Monte Vignale and other localities have yielded an abundant flora of ferns, *Walchia*, &c.[4]

Westwards in the region of the Pyrenees, and in various parts of the Iberian peninsula, rocks believed to be Permian have been recognised. They have in some places furnished marine fossils like those of the Artinsk stage ; in others land-plants, including *Walchia*. They frequently present thick masses of conglomerate, sometimes resting upon Carboniferous rocks, sometimes on formations of older date.[5]

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[1] "Boghead," so named from a place in Linlithgowshire, Scotland, where the substance was first worked for making gas and oil (*ante*, p. 184). The so-called "Boghead" of Autun has been ascertained to contain a large quantity of the remains of gelatinous fresh-water algæ, mingled with the pollen of *Cordaites ;* B. Renault and C. E. Bertrand, *Soc. Hist. Nat. Autun*, 1892.

[2] E. Roche, *B. S. G. F.* sér 3, ix. (1880), p. 78. See also the series of 'Études des Gîtes Minéraux,' published by the Ministry of Public Works in France, particularly the volumes by Delafond on the Autun Basin, and by Mouret on that of Brive ; likewise the Memoirs by Grand' Eury already cited, and his communication in *Compt. rend. Congrès. Géol. Internat.*, Paris (1900), p. 521. Bergeron, 'Etude Géologique du Massif au sud du Plateau Central,' and *B. S. G. F.* sér. 3, vol. xvi. Professor von Reinach, *Z. D. G. G.* (1892), p. 23, gives a careful comparison of the French central plateau Permian rocks with those of the Saar and Nahe.

[3] F. Wallerant, 'Étude Strat. Pétrog. des Maures et de l'Esterel,' 1889, p. 89 ; *Carte Detaill. Géol. France*, Feuille d'Antibes. Michel Lévy, *B. S. G. F.* vii. (1870), p. 763 ; *Bull. Carte Géol. France*, No. 57. Potier, *B. S. G. F.* sér. 3, v. p. 745.

[4] C. De Stefani, "Flore Carbonifere e Permiano," *R. Istitut. Stud. Superior. Sci. Fis. Nat.*, Florence, 1901.

[5] See J. Roussel, "Étude Stratigraphique des Pyrénées," *Bull. Carte Géol. France*, No. 35 (1893). E. de Margerie and F. Schrader, *Ann. Club Alpin. Français*, xviii. (1891). Viguier, 'Études Géol. sur Dept. de l'Aude,' Montpellier (1887), p. 286. Caralp, *B. S. G. F.* (3), xxii. and xxiv.

Alps.[1]—On both sides of the Alpine chain a zone of conglomerates and sandstones, which intervenes between the Trias and older rocks of the region, has been referred in part to the Permian system. The conglomerates (Verrucano[2]) are made up of the detritus of schistose rocks, porphyries, quartz, and other materials of the central core of the mountains. They sometimes contain sheets of porphyry, and occasionally, as at Botzen, they are replaced by vast masses of quartz-porphyry and other volcanic rocks, with tuffs and volcanic conglomerates, indicating vigorous volcanic action. An intercalated zone of shales in the lower conglomeratic and volcanic part of the series in the Val Trompia has yielded *Walchia piniformis*, *W. filiciformis*, *Schizopteris fasciculata*, *Sphenopteris tridactylites*, &c., and serves to mark the Permian age of the rocks containing these plants. Eastwards, at Fünfkirchen, in Hungary, in a corresponding position below the Verrucano conglomerate, a group of younger Permian plants has been found, including species of *Baiera*, *Ullmannia*, *Voltzia*, *Schizolepis*, and *Carpolithus*, nearly half of which occur also in the German Kupferschiefer. Above the conglomerate or the porphyry comes a massive red sandstone called the "Gröden Sandstone," containing carbonised plant-remains. But the most distinctive and interesting feature in the Alpine development of the Permian system is found in the upper portion of the series in the southern region of Tyrol and Carinthia. The red Gröden sandstone is there succeeded by beds of gypsum, rauchwacke, and dolomite, above which comes a bituminous limestone known, from the abundance of species of *Bellerophon*, as the "Bellerophon Limestone." This calcareous member is highly fossiliferous. It contains an abundant marine fauna, which includes numerous species of *Bellerophon*, and species of "*Nautilus*" (so called), *Natica*, *Pecten*, *Aviculopecten*, *Avicula*, *Bakevellia*, *Schizodus*, *Spirifer* (7 species), *Athyris*, *Streptorhynchus*, *Orthis*, *Leptæna*, *Productus*, and *Fusulina*. Nearly all these are peculiar species, but the *Schizodus*, *Bakevellia*, and *Natica* connect the assemblage with that of the Zechstein.

It is interesting to trace in this Bellerophon Limestone an indication of the distribution of the more open sea of Permian time in the European area. While the Zechstein was in course of deposition in isolated Caspian-like basins across the centre of the Continent, calcareous sediments were accumulated on the floor of the opener sea already alluded to as lying to the south, over the site of the present Mediterranean, and stretching eastwards across Russia and the heart of Asia. A portion of this sea-floor has been detected in Sicily, where near Palermo M. Gemmellaro has described the abundant fauna found in its limestones. Foraminifera (*Fusulina*) abound in these rocks, but their most remarkable feature is the number and variety of their cephalopods, which, besides Palæozoic types (*Goniatites*, *Gastrioceras*, *Orthoceras*), comprise many new forms (17 genera and 54 species) akin to the tribe of Mesozoic Ammonites (*Adrianites*, *Agathiceras*, *Cyclolobus*, *Daraelites*, *Medlicottia*, *Parapronorites*, *Popanoceras*, *Stacheoceras*, *Waagenoceras*), also gasteropods (*Bellerophon*, *Pleurotomaria*, &c.) and brachiopods.[3] In the valley of Montenotte, Western Liguria, jaspers have been found among the sericitic schists, containing numerous genera and species of radiolaria, regarded as of Permian age.[4]

[1] E. Suess, *Sitzb. Akab. Wien*, lvii. (1868), pp. 230, 763. G. Stache, *Z. D. G. G.* xxxvi. (1884), p. 367; *Jahrb. k. k. Geol. Reichsanst.* xxvii. (1877), p. 271, xxviii. (1878), p. 93 (giving the fauna of the Bellerophon Limestone); *Verhand. k. k. Geol. Reichsanst.* (1888), p. 320. E. Mojsisovics, 'Die Dolomit-Riffe von Südtirol und Venetien' (1879), chap. iii. Fraas, 'Scenerie der Alpen.' Milch, 'Beiträge zur Kenntniss des Verrucano,' Leipzig, 1896.

[2] The age of this rock, like that of the Flysch, has been long discussed. It has been claimed successively as Liassic, Carboniferous, Triassic, and Permian. It probably represents a peculiar phase of sedimentation which persisted through successive geological periods. See a recent statement on the subject by C. De Stefani, *op. supra cit.* p. 129.

[3] Professor Gemmellaro, 'La Fauna dei Calcari con Fusulina,' &c. Palermo, 1887-89.

[4] C. F. Parona and G. Rovereto, *Atti. Accad. R. Sci. Torino*, xxxi. (1895).

Russia.[1]—The Permian system attains an enormous development in Eastern Europe. Its nearly horizontal strata cover by far the largest part of European Russia. They lie conformably on the Carboniferous system and consist of sandstones, marls, shales, conglomerates, limestones (often highly dolomitic), gypsum, rock-salt, and thin seams of coal. In the lower and more sandy half of this series of strata remains of land-plants (*Calamites gigas*, *Cyclopteris*, *Pecopteris*, &c.) fishes (*Palæoniscus*), and labyrinthodonts occur, but some interstratified bands yield *Productus Cancrini* and other marine shells. The rocks are over wide regions impregnated with copper-ores. The upper half of the series consists of clays, marls, limestones, gypsum, and rock-salt, with numerous marine mollusca like those of the Zechstein (*Productus Cancrini*, *P. horridus*, *Camarophoria Schlotheimii*), but with a rather more abundant fauna, and with intercalated bands containing land-plants.

Much attention has been given in recent years to these rocks, which have now been brought into closer comparison with those of other regions. As developed on the western slope of the Ural Mountains, they have been found to consist of the following groups of strata :—

Red clays and marls, with intercalated sandstones and limestones, almost wholly unfossiliferous, but with a few lamellibranchs resembling *Unio* (*Carbonicola* [*Anthracosia*] *castor* and *C. umbonatus*). This thick group may possibly be partly or wholly Triassic.

Copper-bearing sandstone, permeated with oxide and sulphide of copper, and containing species of *Calamites* (*gigas*), *Sphenopteris* (*lobata*, *erosa*), *Callipteris* (*obliqua*, *conferta*), *Nöggerathia*, *Dadoxylon*, *Knorria*, &c.

Marls, sandstones, and conglomerates with ill-preserved plants (which seem to be on the whole like those of the Artinsk group below), *Carbonicola* (*Unio*) *castor*, *C. umbonatus*, *C. Goldfussiana*, *Archegosaurus*, *Acrolepis*, while some of the sandy marls contain a characteristically marine fauna, *Productus Cancrini*, *P. koninckianus*, *Athyris pectinifera*, and *Spirifer lineatus*.

Gypseous limestones and dolomites.

Artinsk group of sandstones, conglomerates, shales, marls, limestones, and dolomites, stretching from the Arctic Ocean to the Kirgiz Steppes, and lying conformably on the Carboniferous Fusulina Limestone. This group contains a remarkably abundant and varied assemblage of fossils. The plants include species of *Calamites*, *Nöggerathia*, *Sphenopteris*, *Odontopteris*, &c. The fauna comprises a number of common Carboniferous shells such as *Productus semireticulatus*, *P. cora*, *P. longispinus*, *P. scabriculus*, *Orthothetes* (*Streptorhynchus*) *crenistria*, but with these are found many new types of cephalopods like the ammonoid forms above alluded to as occurring in the Bellerophon Limestone of the Tyrol (*Agathiceras*, *Gastrioceras*, *Medlicottia*, *Popanoceras*, *Pronorites*). About 300 species of fossils have been found in the group, of which a half also occur in the Carboniferous system, and only about a sixth in the Permian above.[2]

The recent researches of Professor Amalitzky in the basins of the Soukhona and Dwina in the north of Russia have thrown much light on the Permian deposits of that region and their equivalents elsewhere. These formations comprise examples of marine and continental sedimentation; the latter contain in their lower stages a Lepidodendroid flora of the type of the German Rothliegendes, while in their upper stages, consisting of marls and variegated sandstones, long believed to be unfossiliferous, a rich fauna of fresh-water mollusks and other organisms has been detected. The upper Permian deposits of the lower course of the Soukhona and the upper portion of the Dwina are capable of being grouped as under in descending order :—

[1] See for the earliest descriptions 'Russia and Ural Mountains,' Murchison, De Verneuil, and Keyserling, 4to, 2 vols. 1845.

[2] A. Krasnopolsky, *Mém. Com. Géol. Russ.* xi. (1889), No. 1. A. Karpinsky, *Verhand. k. Min. Gesell. St. Petersbourg*, ix. (1874), p. 267; *Mém. Acad. St. Petersbourg*, 1889. T. Tschernyschew, *Verh. d. k. Min. Ges.*, St. Petersbourg, 1885 ; *Mém. Com. Géol. Russ.* iii. (1889), No. 4.

4. Marls and sandstones (= upper Zechstein) with *Synocladia virgulacea*, *Acanthocladia anceps*, *Edmondia elongata*, *Loxonema Gibsoni*, *L. altenburgensis*, and *Turbo obtusus*.
3. Glossopterian stage, consisting of marls and lenticular sandstones, with the Glossopteris flora and a remarkably varied fauna.
2. Marls and sandstones with a Lower Permian flora (*Callipteris conferta*, *Lepidodendron*, &c.).
1. Sandstones, marls, and sands with a Lower Permian marine fauna (*Geinitzella columnaris*, *Fenestella retiformis*, *Productus Cancrini*, *Macrodon kingianum*, *Nuculana* (*Leda*) *speluncaria*, *Nucula Beyrichii*, *Bakerellia ceratophaga*, *Schizodus rossicus*, *S. planus*, *Streblopteria sericea*, *Murchisonia subangulata*).

The fossils of the third or Glossopterian stage include a considerable number of fresh-water shells (*Palæomutela*, *Oligodon*, *Palæanodonta*, *Carbonicola* [*Anthracosia*], *Anthracomya*), crustaceans of the genus *Estheria* and cyprids, remains of ganoid fishes, together with a large series of vertebrate remains, comprising stegocephalous amphibians, among which some resemble *Melanerpeton* and *Pachygonia*, theromorph reptiles belonging to Pareiasaurians and Dicynodonts, and some that resemble the *Elginia* and *Gordonia* of the Elgin (Triassic) sandstones of the north of Scotland. With these animal remains are associated abundant relics of the Glossopteris flora, comprising the ferns *Glossopteris* (*G. indica*, *G. angustifolia*, *G. stricta*), both as impressions of fronds and as rhizomes (*Vertebraria*), *Gangamopteris major*, *G. cyclopteroides*, *Tæniopteris*, *Sphenopteris*, *Callipteris*, likewise species of *Equisetum*, *Noeggerathiopsis*, and forms resembling the *Schizoneureæ*.[1]

Asia.— The type of sedimentation found in the east and south of Europe extends into Asia. In the valley of the Araxes a limestone occurs containing *Productus horridus*, *Athyris subtilita*, and a number of the ammonoid forms above referred to; while in Bokhara other limestones occur at Darwas which from their cephalopods (*Pronorites*, *Popanoceras*, &c.) probably represent the Artinsk group of Russia. The same character of deposits and of palæontology is still more extensively developed in the Salt Range of the Punjab. In this region the ancient Palæozoic sediments with their saliferous deposits are overlain by a remarkable limestone which has yielded a large assemblage of fossils. At the base of this deposit comes a coarse conglomerate and sandstones followed by the well-known Productus Limestone.[2] The lower portions of the limestone abound in *Fusulina* with Carboniferous brachiopods (*Productus cora*, *P. semireticulatus*, *P. lineatus*, *Athyris Royssii*, *Spirifer striatus*). The cephalopods are numerous and include the ammonoid types (*Cyclolobus*, *Arcestes*, *Medlicottia*, *Popanoceras*, *Xenodiscus*), as well as many Nautili, Orthoceratites, and Gyroceratites. The gasteropods include forms of *Bellerophon*, *Euomphalus*, *Holopella*, *Phasianella*, and *Pleurotomaria*. Lamellibranchs are abundantly represented by such genera as *Allorisma*, *Schizodus*, *Avicula*, *Aviculopecten*, and *Pecten*, but also with others of a distinctly Mesozoic character, as *Lima*, *Lucina*, *Cardinia*, *Astarte*, and *Myophoria*. Yet with these evidences of a newer facies of molluscan life, it is interesting to notice the extraordinary variety and abundance of the brachiopods, including ancient genera such as *Productus* (20 species), *Chonetes*, *Athyris*, *Orthis*, *Leptæna*, and *Streptorhynchus*, mingled with a number of new genera first met with here (*Hemiptychina*, *Notothyris*, *Lyttonia*, *Oldhamia*, &c.). Though the general aspect of this fauna is so unlike that of the Permian rocks of Central Europe, the appearance of a number of Zechstein species links the limestone of Northern India with the European tract. Among these are *Camarophoria humbletonensis*, *Strophalosia excavata*, *S. horrescens*, *Spiriferina cristata*.

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[1] Amalitzky, *Soc. Imp. Nat.* St. Petersbourg, 1899; *Compt. rend.* cxxxii (1901), p. 591, and *Q. J. G. S.* li. (1895), p. 337.

[2] W. Waagen, *Mem. Geol. Surv. India*, 'Salt Range Fossils,' vol. i. Productus Limestone, 1879-88; *Palæont. Indica*, 1888, 1891. Diener, *Mem. Geol. Surv. India*, Part iii., 1897.

This oceanic type of deposit, however, does not seem to extend southwards across the Indian peninsula. South of the line of the Narbada River a totally different series of sedimentary formations occurs. In that southern region, as has already been stated (p. 1058), the lower and middle Mesozoic marine rocks and the upper part of the Palæozoic series of other countries are represented by a vast thickness of strata, chiefly sandstones and shales, probably almost entirely of fluviatile origin. To this great fresh-water accumulation the name of Godwána system has been given by the Geological Survey of India. The exceedingly coarse Talchir conglomerates in the lowest group of the series have been above noticed among the Carboniferous formations. The Talchir is succeeded by the Karharbari group, marked by the occurrence of seams of excellent coal and an abundant flora, which includes a number of species of *Gangamopteris* and *Glossopteris*, with some cycads (*Glossozamites*), conifers (*Voltzia, Albertia*) and the doubtful *Noeggerathiopsis*. The overlying Damuda series consists chiefly of sandstones and shales with ironstones, and nearly all the valuable coal-seams of the Indian peninsula, and attains a thickness of 10,000 feet. It has yielded an abundant flora, in which species of *Glossopteris* and *Gangamopteris* are prominent, while some rare vertebrates have likewise been found in it (*Gondwanosaurus*, a labyrinthodont allied to *Archegosaurus* and *Brachyops*). This great mass of sediments is probably homotaxial with the Permian or Permo-Carboniferous formations of other regions. In the Salt Range the upper part of the Productus-beds, as above stated, is probably referable to the Permian system. It is overlain, without visible unconformability, by the Chidra group, only about 15 feet thick, in which the fossils are less Palæozoic in aspect than those of the groups below, seeing that nearly half of them have Mesozoic affinities and only four species are identical with Permian species of other countries.[1] The Panchet series which succeeds is more probably Triassic, while the upper subdivisions of the Gondwana system are of Jurassic age.[2]

In north-western Afghanistan a series of coal-bearing sandstones, believed to be the equivalents of the Gondwana system of India, terminates downwards in a group of shales altered into mica-schists with graphitic and anthracitic seams and impure limestone, the whole invaded by granite. It is interesting to note that towards the base of this series a coarse conglomerate or boulder-bed occurs, precisely similar to that of the Talchir group. Beneath it lies a dark limestone with casts of brachiopods. This series of strata was referred by Mr. Griesbach, who first described it, to a Permo-Carboniferous age. It passes upward into what are evidently Triassic rocks (*postea*, p. 1107).[3]

Australia.—The remarkable coal-bearing series of the Australian colonies with its boulder-beds, which has been termed Permo-Carboniferous, has been described above (p. 1059). No satisfactory line can be drawn there between Carboniferous and Permian types, while on the other hand, the highest members of the series are separated from the next overlying formation sometimes, though not always, by an unconformability, and more especially by the abrupt change in the character of the fossil flora, which has been referred provisionally to the Triassic system.

Africa.—Throughout a vast extent of the centre and south of this continent, a group of rocks known as the Karoo series presents some of the lithological and palæontological types of southern India and south-eastern Australia. It lies unconformably on everything older than itself, and has been separated into three groups. Of these (1) the lowest has already been referred to (p. 1057) as composed of the Dwyka Conglomerate, surmounted by the Ecca mudstones and shales. In these dark friable argillaceous beds, a flora has been found which presents a remarkable resemblance to that of the lower members of the great Gondwana series of India. Some of the species are actually

[1] Medlicott and Blanford, 'Manual of Geology of India,' 2nd edit. by R. D. Oldham, p. 128.

[2] *Op. cit.* chaps. vii. and viii.

[3] Griesbach, *Records Geol. Surv. India*, xix. (1886), p. 239.

identical in the two countries, such as *Glossopteris browniana*, *Gangamopteris cyclopteroides*, and *Noeggerathiopsis Hislopi*. The middle division (2) or Beaufort group, which extends in nearly horizontal sheets over a vast region, consists of sandstones, shales, often carbonaceous, with seams of coal and intercalated sheets of diabase. It contains a mingling of Carboniferous genera of plants (*Sigillaria*) with the characteristic Glossopteris-flora, and of the latter a number of the species are common to the Damuda rocks of India, such as *Glossopteris browniana*, *G. angustifolia*, *G. communis*, *G. stricta*, *G. retifera*, and *G. damudica*.[1] The Beaufort beds have yielded a remarkable reptilian fauna. The most striking feature, indeed, in the Karoo series is the extraordinary number and variety of its Anomodonts, which here reach their culmination. The families of the Pareiasaurs, the Tapinocephalids, the Galesaurians, the Dicynodonts and the Endothiodonts seem to have had their chief habitat in Southern Africa. Of this interesting fauna the Beaufort beds have furnished a large share. It may be remarked that some of the species have representative forms in the meagre fauna of the Lower Gondwana rocks of India.

North America.—The Permian system is represented in the United States by a series of strata which graduate downward into the Coal-measures and, where their top is seen, pass upward more or less gradually into what are believed to be representatives of the Trias, but which do not furnish any strongly-marked palæontological features. They have accordingly been classed by many geologists as Permo-Carboniferous. In the great Appalachian coal-field, as well as Prince Edward Island, Nova Scotia and New Brunswick, the uppermost coal-bearing group (see p. 1061) is overlain conformably by a group of strata, upwards of 1000 feet thick, which in Pennsylvania was called the "Upper Barren Measures." At its base lies a massive conglomeratic sandstone, above which come sandstones, shales, and limestones, with thin coals, the whole becoming very red towards the top. Professors W. M. Fontaine and I. C. White have shown that, out of 107 plants examined by them from these strata, 22 are common to the true Pennsylvanian Coal-measures and 28 to the Permian rocks of Europe; that even where the species are distinct they are closely allied to known Permian forms; that the ordinary Coal-measure flora is but poorly represented in the "Barren Measures," while on the other hand, vegetable types appear of a distinctly later time, forms of *Pecopteris*, *Callipteridium*, and *Saportæa* foreshadowing characteristic plants of the Jurassic period. These authors likewise point to the indications furnished by the strata themselves of important changes in the physical condition of the American area, and to the remarkable paucity of animal life in these beds, as in the red Permian rocks of Europe. Some drab-coloured limestones crowded with ostracods may be compared with the Spirorbis Limestones of Central England. The evidence seems certainly in favour of regarding the upper part of the Appalachian coal-fields as representing the reptiliferous beds overlying the Coal-measures at Autun and their equivalents.[2] In Nova Scotia and the neighbouring regions a similar upward passage has been observed from true Coal-measures into a group of reddish strata containing Permian types of vegetation.

To the west and south-west of the Appalachian region the Permian type becomes more developed, and in Kansas and Texas acquires considerable importance. In the former State, the uppermost Coal-measures are overlain by a series of thin limestones, and yellowish, green and chocolate shales (Neosho formation of Prosser) having a united thickness of 130 feet and numerous marine fossils (*Productus semireticulatus*, *Chonetes granulifera*, *Derbya crassa*, *Athyris subtilita*, *Pseudomonotis Hawni*, *Aviculopecten occidentalis*, *Pleurophorus subcostatus*, *Meekella striato-costata*, &c.). Above these strata lies a middle group (Chase) of limestones and shales, with a number of bands of flint, the whole having a thickness of about 265 feet, and containing

[1] Feistmantel, *Abhandl. Böhm. ges. Wissensch.* vii. 3 (1889).

[2] "On the Permian or Upper Carboniferous Flora of W. Virginia and S.W. Pennsylvania," *Second Geol. Surv. Penn. Report*, P.P. 1880.

many mollusks, including species of *Bakevellia*, *Pleurophorus*, *Aviculopecten*, *Edmondia*, *Derbya*, *Productus*, *Chonetes*, *Spirifer*, &c. The upper group (Marion) consists of about 400 feet of limestones, and in the uppermost part, shales, marls, and gypsum. Its fossils are, on the whole, similar to those in the groups below.[1] The Kansas Permian formations extend northwards into Nebraska, where they have likewise yielded an abundant marine fauna.[2] They spread southwards into Texas, where also a threefold subdivision of them has been made, the lower group being termed Wichita, the middle Clear Fork, and the upper Double Mountain. The Wichita beds contain a flora like that of the "Upper Barren Measures" of West Virginia and Pennsylvania, and comprise a number of species of *Pecopteris* and *Callipteridium*, together with *Callipteris conferta*, *Odontopteris nervosa*, *Goniopteris oblonga*, *Sphenophyllum*, and *Walchia*. The marine bands have yielded species of *Goniatites*, *Ptychites*, *Medlicottia*, *Popanoceras*, *Orthoceras*, *Nautilus*, &c.[3] From those strata also and the "Clepsydrops shales" of Illinois a number of fish, stegocephalous amphibia, and rhynchocephalous reptiles have been obtained.[4]

Spitzbergen. The Permian sea appears to have extended far within the Arctic circle, for above the Carboniferous rocks of Spitzbergen there occurs a group of strata which contain Permian marine forms (*Productus*, *Streptorhynchus*, *Retzia*, *Pseudomonotis Bakevellia*, &c.[5]

PART III. MESOZOIC OR SECONDARY.

Though no geologist now admits the abrupt lines of division which were at one time believed to mark off the limits of geological systems and to bear witness to the great terrestrial revolutions by which these systems were supposed to have been terminated, nevertheless the influence of the ideas which gave life to these banished beliefs is by no means extinct. The threefold division of the stratified rocks of the terrestrial crust into Primary, Secondary, and Tertiary, or, as they are now called, Palæozoic, Mesozoic, and Cainozoic, is a relic of those ideas. This threefold arrangement is retained, however, not because each of these great periods of geological time is thought to have been separated by any marked geological or geographical episode from the period which preceded or that which followed it, but because, classification and subdivision being necessary in the acquisition of knowledge, this grouping of the earth's stratified formations into three great series is convenient. In our survey of the older members of these formations we have come to the end of the first series of fossiliferous systems, and are about to enter upon the consideration of the second. But we find no indication in the rocks of any general break in the continuity of the processes of sedimentation

[1] C. S. Prosser, *Bull. Geol. Soc. America*, vi. (1894), p. 26; *Journ. Geol.* iii. (1895), pp 682,764; *University Geol. Surv. Kansas*, ii. (1897), p. 51.

[2] W. C. Knight, *Journ. Geol.* vii. (1899), p. 357. This paper contains a list of the invertebrate Permian fossils of Kansas, Nebraska and partly of Texas, with columns showing the geographical range of the genera in the Old world and the New. See also the paper by C. R. Keyes on "American Homotaxial Equivalents of the Original Permian," in the same vol. p. 321.

[3] C. A. White, *Amer. Naturalist*, February 1889; *B. U. S. G. S.* No. 77 (1891); I. C. White, *Bull. Geol. Soc. Amer.* iii. (1892) p. 217.

[4] E. D. Cope, *Proc. Amer. Phil. Soc.* xvii. (1877-78), pp. 182, 505.

[5] B. Lundgren, *Bihang. Svensk. Vet. Akad. Handl.* xiii. (1887); *Neues Jahrb.* 1891.

and of life which we have seen to be recorded among the Palæozoic rocks. On the contrary, so insensibly do the Palæozoic formations in many places merge into the Mesozoic, that not only can no sharp line be drawn between them, but it has even been proposed to embrace the strata at the top of the one series and the base of the other as parts of a single continuous system of deposits.

Nevertheless, when we look at the Mesozoic rocks as a whole, and contrast them with the Palæozoic rocks below them, certain broad distinctions readily present themselves. Whereas in the older series mechanical sediments form the prevalent constituents, piled up in masses of greywacke, sandstone, conglomerate, and shale often many thousands of feet in thickness, in the newer series limestones play a much more conspicuous part. Again, while in the Palæozoic formations a single kind of sediment may continue monotonously persistent for many hundreds or even thousands of feet of vertical depth, in the Mesozoic series, though thick accumulations of one kind of material, especially limestone, are locally developed, there is a much more general tendency towards frequent alternations of different kinds of sedimentary material, sandstones, shales, and limestones succeeding each other in rapid interchange. Another contrast between the two series is supplied by the very different extent to which they have suffered from terrestrial disturbances. Among the Palæozoic rocks it is the rule for the strata to have been thrown into various inclined positions, to have been dislocated by faults and in many regions to have been crumpled, pushed over each other, and even metamorphosed. The exceptions to this rule are so few that they are always signalised as of special interest. Among the Mesozoic rocks, on the contrary, the original stratification-planes have usually been little deranged, faults are generally few and trifling, and it is for the most part only along the flanks or axes of great mountain-chains that extreme dislocation and disturbance can be observed. A further distinction is to be found in the relation of the two series to volcanic activity. We have seen in the foregoing chapters that every period of Palæozoic time has been marked somewhere in the Old World by volcanic eruptions, that in certain regions, such as that of the British Isles, there has been an abundant outpouring of volcanic material again and again in successive geological periods within the same limited area, and thus that masses of lava and tuff thousands of feet in thickness, and sometimes covering hundreds of square miles in extent, have been thrown out at the surface. But in the European area, with some trifling exceptions at the beginning, the whole of the Mesozoic ages appear to have been unbroken by volcanic eruptions. The felsites, rhyolites, andesites, diabases, basalts, and other lavas and eruptive rocks so plentiful among the Primary formations are generally absent from the Secondary series.

But perhaps the most striking, and certainly the most interesting, contrast between the rocks of the older and the newer series is supplied in their respective organic remains. The vegetable world undergoes a remarkable transformation. The ancient preponderance of cryptogamic forms now ceases. The antique types of Sigillaria, Stigmaria, Lepido-

dendron, Calamites, and their allies disappear from the land, and their places are taken by cycads and conifers, while eventually the earliest dicotyledons come as the vanguard of the rich flora of existing time. Nor are the changes less marked in the animal world. Such ancient and persistent types as the cystideans, blastoids, and trilobites had now wholly vanished. The crinoids, that grew so luxuriantly over the sea-floor in older time, now flourished in greatly diminished numbers, while the sea-urchins, which had previously occupied a very subordinate position, took their place as the most conspicuous group of the echinoderms. The brachiopods, which from the remotest time had filled so prominent a place, now rapidly diminished in number and variety. But perhaps the most striking biological feature which meets us as we pass from the Palæozoic into the Mesozoic formations is the apparently sudden and prodigious development of the cephalopods. We have seen, indeed, in the foregoing pages that the advent of these varied types of higher molluscan life was already heralded by the appearance of a number of their genera in strata believed to be of Permian age. But the extent and importance of this feature in the history of the invertebrates was not recognised until the open sea deposits of Triassic time were explored in Southern Europe and India. It was then found that the Ammonoids attained their culmination in the early ages of Mesozoic time. So sudden is their expansion in variety of type in the Trias that we are constrained to believe that a vast interval of time must have elapsed, which is inadequately represented either by sedimentary formations or by organic remains, between the known Permian formations and those of the pelagic Trias. The Orthoceratites which had played so prominent a part throughout the Palæozoic ages disappeared in the early part of Mesozoic time. The Goniatitoids were likewise waning, to be replaced by the Ceratitoids, which were the dominant types in the first Mesozoic period. But the characteristic forms through the rest of the periods were the various tribes of Ammonites. These, however, all died out before Tertiary time. The dibranchiate cephalopods now made their appearance, and in the belemnoids soon reached a remarkable development, only, however, to decline, until they too had almost died out when the Tertiary ages began. They are represented by only a single living genus. Another distinctive feature of the fauna was the variety and abundance of reptilian life. The labyrinthodont amphibians were replaced by many new reptilia, such as the Ichthyosaurs, Plesiosaurs, Ornithosaurs, Deinosaurs, and Crocodiles. It was in Mesozoic time also that the first mammals made their appearance in marsupial forms, which remained the highest types that were reached before the beginning of the Cainozoic periods.

The Mesozoic formations have been grouped in three great divisions, which, though first defined in Europe, are found to have their representative series of rocks and fossils all over the world. The oldest of these is the Trias or Triassic system, followed by the Jurassic and Cretaceous.

Section i. Triassic.

It has been already mentioned that the great mass of red rocks, which in England overlies the Carboniferous system, was formerly classed as New Red Sandstone, but is now divided into two systems. We have considered the lower of these under the name of Permian. The general facies of organic remains in that division is still decidedly Palæozoic, though with clear indications of the coming of new types of life. Its brachiopods and plants connect it with the Carboniferous rocks below; a number of its cephalopods link it with the Trias above. It forms the close of the long series of Palæozoic formations. When, however, we enter the upper division of the red rocks, though the general lithological characters remain in most of Europe very much as in the lower group, the fossils bring before us the advent of the great Mesozoic flora and fauna. This group therefore is put at the base of the Mesozoic or Secondary series, though in some regions, as in England, no very satisfactory line of demarcation can always be drawn between Permian and Triassic rocks. The term Trias was suggested by F. von Alberti in 1834, from the fact that in Suabia, and throughout most of Germany, the group consists of three well-marked subdivisions.[1] But the old name, New Red Sandstone, is familiarly retained by many geologists in England. The word Trias, like Dyas, is unfortunately chosen, for it elevates a mere local character into an importance which it does not deserve. The threefold subdivision, though so distinct in Germany, disappears elsewhere.

§ 1. General Characters.

As the term Trias arose in Germany, so the development of the Triassic rocks in that and adjoining parts of Europe was long accepted as the normal type of the system. There can be little doubt, however, that though this type is best known, and has been traced in detached areas over the centre and west of Europe, from Saxony and Franconia to the north of Ireland, and from Basle to the Germanic plain, reappearing even among the eastern States of North America, it must be looked upon as a local phenomenon. This assertion commends itself to our acceptance, when we reflect upon the nature of the strata of the central European Triassic basins. These rocks consist for the most part of bright red sandstones and clays or marls, often ripple-marked, sun-cracked, rain-pitted, and marked with animal footprints. They contain layers, nodules, or veinings of gypsum, beds (and scattered casts of crystals) of rock-salt, and bands or massive beds of limestone, often dolomitic. Such an association of materials points to isolated basins of deposit—salt-lakes or inland seas—to which the outer sea found occasional access, and in which the water underwent concentration, until its gypsum and salt

[1] 'Beitrag zu einer Monographie des Bunten Sandsteins, Muschelkalks, und Keupers und die Verbindung dieser Gebilde zu einer Formation,' Stuttgart, 1834, p. 324. Thirty years later the same observer published his 'Ueberblick über die Trias,' 1864, and gave a synopsis of the Triassic literature of that interval.

were thrown down. That the intervals of diminished salinity, during which the sea renewed, and perhaps maintained, a connection with the basins, were occasionally of some duration, is shown by the thickness and fossiliferous nature of the limestones.

It is evident, however, that in this, as in all other geological periods, the prevalent type of sedimentation must have been that of the open sea. The thoroughly marine or pelagic equivalents of the red rocks of the basins have now been traced over a far wider portion of the earth's surface. In the Mediterranean basin and thence eastward through the Carpathian Mountains and Southern Russia into the heart of Asia and Northern India, the deposits of the open Triassic sea are well developed. Masses of limestone and dolomite, attaining sometimes a thickness of several thousand feet, are there replete with a characteristically marine fauna. The same fauna has been detected over a wide region of the north of Asia from Spitzbergen to Japan, the western regions of North and South America, in New Zealand, and in Southern Africa.

The German or lagoon type of the system has been divided into three formations, as its name denotes; the lower being called Bunter, the middle Muschelkalk, and the upper Keuper. It is evident, however, that this classification, being founded mainly on lithological characters, can only be of local application even in areas where the same type of sedimentation prevails. A nomenclature capable of general use must be based on the pelagic development of the system and on the evidence of organic remains. The Austrian geologists, from a study of the distribution of the cephalopoda throughout the formations in the Mediterranean Triassic province and their extension into India, have proposed a division into two great sections, the lower consisting of two series of formations with distinct palæontological zones, and the upper formed also of two formations and a number of zones, the whole being capped by the Rhætic group or zone of *Avicula contorta*. This classification will be found in tabular form on p. 1106.

LIFE.—The flora of the Triassic period appears to have been more closely similar to that of Jurassic than to that of Permian time, the Palæozoic types, such as *Calamites*, *Lepidodendron*, and *Sigillaria*,[1] now becoming extinct. It consisted mainly of ferns (some of them arborescent), equisetums, conifers, and cycads. Among the ferns, a few Carboniferous genera (*Sphenopteris*, *Pecopteris*, *Cyclopteris*) still survived, together with *Glossopteris*, *Tæniopteris*, *Caulopteris*, and other old genera, but new forms appeared (*Anomopteris*, *Acrostichites*, *Cladophlebis*, *Clathropteris*, *Danæopsis*, *Lepidopteris*, *Lonchopteris*, *Laccopteris*, *Merianopteris*, *Neuropteridium* (*Crematopteris*), *Sagenopteris*, *Thinnfeldia*). The earliest undoubted horse-tail reeds appear in the Carboniferous rocks, but they become common in this system, where they are represented by the two genera *Equisetites* and *Schizoneura*. The conifers are represented by *Voltzia*, the cypress-like or spruce-like twigs of which are specially characteristic organisms of the Trias (Fig. 415), and by *Albertia*, *Abietites*, *Araucarites*, *Arau-*

[1] *Sigillaria* and *Glossopteris* are associated together among strata in South Africa which have been regarded as possibly of Triassic age, *Q. J. G. S.* liii. (1897), pp. 310-340.

carioxylon, *Brachyphyllum*, *Palissya*, &c. The Ginkgoaceæ are represented by *Baiera*, and in the United States a grass-like plant has been found (*Torkia*). But the most distinctive feature in the flora of the earlier Mesozoic ages was the great development of cycadaceous vegetation. The most abundant genus is *Pterophyllum*; others are *Anomozamites*, *Ctenophyllum*, *Cycadeospermum*, *Cycadites*, *Nilssonia*, *Otozamites*, *Podozamites*, *Ptilophyllum*, *Sphenozamites*, *Zamiostrobus*, and *Zamites*. So typical are these plants that the Mesozoic formations have been classed as belonging to the "Age of Cycads." Calcareous algæ (*Gyroporella*, &c.) abounded in the open seas of the time and contributed to the growth of limestone reefs.

Fig. 414. Voltzia heterophylla, Brongn.

The fauna is exceedingly scanty in the red sandy and marly strata of the central European Trias, and comparatively poor in forms, though often abundant in individuals, in the calcareous zones of the same region. From the Alpine development, a much more varied suite of organisms has been disinterred. Some of the Alpine limestones are full of foraminifera (*Orbulina*, *Globigerina*), others contain numerous calcareous sponges (*Eudea*, *Corynella*, *Stellispongia*, *Peronidella*, &c.). Corals abound in some localities in the same rocks, occasionally forming true reefs. They do not include any typical rugose forms, which had died out in Palæozoic time, but show a great variety of perforate types (*Thamnastræa*, *Astræomorpha*, *Spongiomorpha*, *Heptastylis*, *Stromatomorpha*), and of aporose forms (*Montlivaltia*, *Stylophyllum*, *Isastræa*, *Calamophyllia*, *Thecosmilia*, *Stylina*).

All the Palæozoic families of Echinoderms had now disappeared, but two groups of crinoids begin to attain prominence in genera of Encrinidæ and Pentacrinidæ, some of which are plentiful among the limestones, particularly crinoid-stems, of which these rocks are in some cases almost wholly composed. One of the most characteristic fossils of the

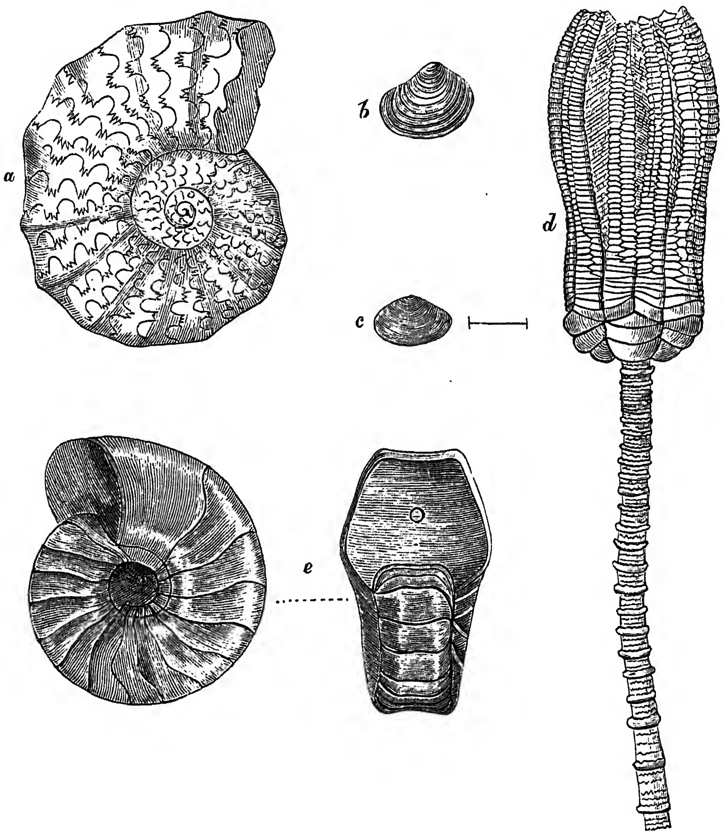

Fig. 415.—Triassic Fossils.

a, Ceratites nodosus, De Haan. ; *b*, Estheria minuta, Goldf. (?) ; *c*, Tapes? (Pullastra) arenicolus, Strickland (nat. size and enlarged); *d*, Encrinus liliiformis, Schloth. (nat. size); *e*, Temnocheilus (Nautilus) bidorsatus, Schloth. (½).

Muschelkalk is the crinoid *Encrinus liliiformis* (Fig. 415, *d*). Species of urchins (especially forms related to *Cidaris*) are common in the Alpine Trias. An abundant fossil in some of the upper Triassic and Rhætic shales is the little phyllopod *Estheria* (Fig. 415, *b*). Ostracods[1] also abound in some shales (*Darwinula*, *Cytheridea*). Decapod Crustacea now made their appearance, replacing the extinct trilobites. Long-tailed

[1] On the Rhætic ostracods of Britain, T. Rupert Jones, *Q. J. G. S.* l. (1894), p. 156.

forms, like our living shrimps and prawns, were represented (*Penæus*, *Æger*, *Pemphix*, &c.). The Brachiopods, while showing some resemblances to those of Palæozoic time, present on the whole a great contrast to these in their comparatively diminished numbers, and in the final disappearance of some of the ancient genera. Thus the families of the Strophomenidæ, Centronellidæ, and Athyridæ make their last appearance, while, on the other hand, the Terebratulidæ, Rhynchonellidæ, and Koninckinidæ attain a great development.

While the brachiopods were waning the Lamellibranchs were taking a more prominent place in the molluscan fauna, and in the Triassic seas they had already established the predominance which they have maintained down to the present day. Some of the older genera now died out, such as *Solenopsis* and *Allorisma*, while a large number of new forms made their appearance. Among these new-comers were *Limopsis*, true Unios, *Dimya*, the Pholadomyacidæ, Pleuromyacidæ, Astartidæ, Lucinaceæ, Cardiidæ, and Corbulidæ. One of the most distinctively Triassic genera is *Myophoria*, of which there is a great abundance and variety of species. Other common genera are *Pecten* (*Pleuronectites*), *Halobia* (*Daonella*), *Trigonodus*, *Pachycardia*, *Monotis*, *Gervillia* (*Hœrnesia*), *Anoplophora*, *Avicula*, *Cardium* (*Protocardia*), *Cardita*, *Megalodus*, *Nucula*, *Cassianella* (*Tapes?* Fig. 415, *c*). Among numerous Gasteropods we find that the families of the Neritidæ, Eulimidæ, Naticidæ, Turritellidæ, Nerineidæ, and Cerithiidæ now take their rise. The Nautiloidea were manifestly waning in importance, while the Ammonoidea reached the striking development above referred to. In no respect is the contrast between the palæontological poverty of the German, and the richness of the Alpine Trias so marked as in the development of cephalopods in the respective regions. In the former area the Nautiloidea are represented by a few species of *Temnocheilus* (*Nautilus*) (*T. bidorsatus*, Fig. 415, *e*), the Ammonites by species of *Ceratites* (*C. nodosus*, Fig. 415, *a; C. semipartitus*). In the Alpine limestones, however, there occurs a profusion of cephalopod forms, among which a remarkable commingling of Palæozoic and Mesozoic types is noticeable. The genus *Orthoceras*, so typical of the Palæozoic rocks, has never yet been met with in the German Triassic areas; but it appears in the Alpine Trias in species which do not differ much from those of the older formations. Associated with it are some new Nautiloid forms (*Clymenonautilus*, *Clydonautilus*, *Pleuronautilus*). It is especially interesting, amid these examples of the persistence of primeval forms, to notice the advent of the earliest precursors of types which played a conspicuous part in the animal life of later periods. Thus among the dibranchiate cephalopods, the family of the Belemnites, which appeared so prominently among the denizens of the Mesozoic seas, had its earliest known forms in the open Triassic waters of the Alpine region (*Aulacoceras*, *Atractites*). Though the earliest Ammonites had appeared long before, it was not until Triassic time that this great order assumed the importance which it maintained all through the Mesozoic ages. So long as only the German type of the Trias had been studied, this early development was not known. But we have now learnt that the Ammonoidea really attained

their culmination in Triassic time, more than 1000 Triassic species having been described. In the open seas which then spread over Southern Europe and extended into Asia, into America, and even into the Arctic regions, there flourished an altogether extraordinary profusion and variety of cephalopod life, as may be gathered from the following list of some of the generic types—*Nannites*, *Otoceras*, *Halorites*, *Tropites*, *Pharciceras*, *Sageceras*, *Hedenstroemia*, *Lecanites*, *Badiolites*, *Flemingites*, *Meekoceras*, *Prionites*, *Ptychites*, *Ægoceras*, *Hungarites*, *Celtites*, *Sibirites*, *Danubites*, *Tirolites*, *Dinarites*, *Buchites*, *Arpadites*, *Trachyceras*, *Tibetites*, *Pinacoceras*, *Choristoceras*, *Rhabdoceras*, *Cochloceras*, *Norites*, *Lobites*, *Popanoceras*, *Arcestes*, *Didymites*, *Cladiscites*, *Megaphyllites*, *Rhacophyllites*.

The fishes of the Triassic period include teeth and spines of selachians (*Hybodus*, *Acrodus*), scales, teeth, or exoskeletons of ganoids (*Gyrolepis*, *Dapedius*, *Dictyopyge*, *Semionotus*, *Lepidotus*, *Nephrotus*, *Saurichthys*, *Eugnathus*) and teeth of the dipnoan genus *Ceratodus*.

One of the distinctive palæontological features of the Trias is the remarkable assemblage of amphibian and reptilian remains found in it. The ancient order of Stegocephalia (Labyrinthodonts) still flourished; numerous prints of their feet have been observed on surfaces of sandstone beds (*Cheirotherium* or *Cheirosaurus*), and the bones of some of them have been found (*Labyrinthodon*, *Trematosaurus*, *Mastodonsaurus*, *Capitosaurus*, *Metopias*, *Diadetognathus*, &c.). The Reptilian class was well represented. Anomodonts were especially abundant and varied in form—*Pareiasaurus*, *Tapinocephalus*, *Titanosuchus*, *Galesaurus*, *Cynosuchus*, *Dicynodon*, *Oudenodon*, *Endothiodon*, *Procolophon*. Of the rhynchocephalous types which first appeared in Permian time, and are almost extinct at the present day, bones and even nearly entire skeletons have been discovered in the Trias, the most important genera being *Hyperodapedon*, *Rhynchosaurus*, and *Telerpeton*. The earliest deinosaurs yet certainly known occur in this system (*Thecodontosaurus*, *Zanclodon* [*Teratosaurus*, *Plateosaurus*], *Palæosaurus*, *Cladyodon*, *Ammosaurus*, *Anchisaurus*, &c.).[1] These long-extinct types of reptilian life presented characters in some measure intermediate between those of the ostriches and true reptiles, and their size and unwieldiness gave them a resemblance to the elephants and rhinoceroses of modern times. They appear to have walked mainly on their strong hind legs, the prints of their hind feet occurring in great abundance among the red sandstones of Connecticut (Fig. 211). Many of them had three bird-like toes, and left footprints quite like those of birds. Others had four or even five toes, and attained an enormous size, for a single footprint sometimes measures twenty inches in length.

The ichthyosaurs and plesiosaurs, which played so foremost a part in the reptilian life of Mesozoic time, had their Triassic forerunners (*Mixosaurus*, *Nothosaurus*, *Simosaurus*, *Pachypleura* = *Neusticosaurus*). Of higher grade were the earliest types of crocodiles, the remains of which

[1] See on deinosaurs of the Trias, Huxley, *Q. J. G. S.* xxvi. 32. Marsh, *Amer. Journ. Sci.* xxxvii. (1889), p. 331; xlii. (1891), p. 267; xliii. (1892), p. 542; xlv. (1893), p. 169; l (1896), p. 491; *Geol. Mag.* (1893), p. 150; (1896), p. 388; (1897), p. 38; (1898), p. 6; (1899), p. 157; 16th *Ann. Rep. U.S. G. S.* (1896), pp. 143-244.

have been detected in Triassic rocks. They belong to an extremely generalised type, and appear to have been widely distributed. *Stagonolepis* and *Erpetosuchus* occur among the other reptilian remains at Elgin,[1] while *Belodon* (*Phytosaurus*) has been obtained in Germany, India, and North America.

It may be remarked here, with reference to the occurrence of reptilian remains, that though they may be rare throughout a system, they are not infrequently met with in considerable numbers at some particular part of a deposit. Thus in Britain, a specially prolific locality for them has been the district of Elgin in the north of Scotland, formerly believed to be Upper Old Red Sandstone. This rock contains the remains chiefly in the form of empty casts. Besides the small lizard, *Telerpeton*, described by Mantell in 1852, as well as the larger possibly allied form *Hyperodapedon*, the sandstone has yielded a number of new forms of anomodonts which present a curious resemblance to those found in the South African Karoo beds. These skulls and skeletons have been skilfully worked out and described by Mr. E. T. Newton of the Geological Survey.[2] One of them, *Gordonia*, was nearly allied to *Dicynodon* (Owen), *Geikia* was closely related to *Ptychognathus*, while *Elginia* was a remarkable many-horned animal distinctly allied to *Pareiasaurus* (Owen). The same sandstones have yielded the crocodiles *Stagonolepis*, *Erpetosuchus*, and *Ornithosuchus*. Again, a slab of the "Stubensandstein" near Stuttgart was obtained in the year 1877 on which lay twenty-four individuals of another crocodile, *Aëtosaurus*.[3] But perhaps the most remarkable assemblage of Triassic vertebrates has been obtained from the Karoo formation of South Africa. These remains include Labyrinthodonts (*Micropholis*, *Petrophryne*), Anomodonts (*Tapinocephalus*, *Pareiasaurus*, *Anthodon*), Rhynchocephalia (*Saurosternon*), and a large number of genera belonging to a remarkable carnivorous order, the Theriodonts, distinguished by having three sets of teeth, like those of carnivorous mammals (*Lycosaurus*, *Tigrisuchus*, *Cynodraco*, &c.). There were likewise examples of Dicynodonts, characterised by having no teeth, or by a single tusk-like pair, the jaws being probably prolonged into a horny beak. The limbs of these creatures were well developed, and the animals probably walked on the land (*Dicynodon*, *Oudenodon*, &c.).[4]

It has been supposed that evidence of the existence of Triassic birds is furnished by the three-toed footprints above referred to. But probably these are mostly, if not entirely, the tracks of deinosaurs, the

[1] On the Crocodilian remains of the Elgin Sandstone see Huxley, *Q. J. G. S.* 1859; *Mem. Geol. Surv.* Monograph iii. 1877; and E. T. Newton's Memoirs, *Phil. Trans.* vols. clxxxiv. and clxxxv. (1893-94). A new form from the Elgin Sandstone, named by E. T. Newton *Ornithosuchus*, is regarded by him as probably deinosaurian (*Phil. Trans.* clxxxv. (1894), B. p. 601.

[2] In the memoirs cited in the foregoing note.

[3] O. Fraas, *Jahrb. Ver. Nat. Würtemberg*, xxxiii. (1877). It may be remarked also that the recent discovery by Professor Amalitzky of abundant Permian reptiles (p. 1069) was made from lenticles of sandstone in what had been supposed to be unfossiliferous strata.

[4] Owen's 'Catalogue of Fossil Reptilia of South Africa,' Brit. Museum, 1876.

absence of two pairs of prints in each track being accounted for by the bird-like habit of the animals in the use of their hind feet in walking. One of the most noteworthy facts in the palæontology of the Trias is the occurrence in this system of the first relics of mammalian life, in what are believed to be detached teeth and lower jaw-bones. These have been referred to small Prototheria which present some resemblance to the *Myrmecobius*, or Banded Ant-eater of New South Wales. The European genus is *Microlestes*. In the Trias of North Carolina a supposed marsupial has been described under the name of *Dromatherium*. It is possible, however, that some of these organisms may be reptilian.

§ 2. Local Development.

Britain.[1]—Triassic rocks occupy a large area of the low plains in the centre of England, ranging thence northwards along the flanks of the Carboniferous tracts to Lancaster Bay, and southwards by the head of the Bristol Channel to the south-east of Devonshire. They have been arranged in the following subdivisions :—

Rhætic.[2]	Penarth beds.—Red, green, and grey marls, black shales, and "White Lias" (20 feet or less up to 150 feet).
Upper Trias or Keuper.	Upper Keuper or New Red Marl.—Red and grey shales and marls, with beds of rock-salt and gypsum (800 to 3000 feet). Lower Keuper Sandstone.—Thinly laminated micaceous sandstones and marls (Waterstones), passing downwards into white, brown, or reddish sandstones, with a base of conglomerate or breccia (150 to 250 feet).
Lower Trias (or Bunter (1000 to 2000 feet).	Upper Mottled Sandstone.—Soft bright red and variegated sandstones, without pebbles (200 to 700 feet). Pebble-beds.—Harder reddish-brown sandstones with quartzose pebbles, passing into conglomerate; with a base of calcareous breccia (60 to more than 1000 feet). Lower Mottled Sandstone.—Soft bright red and variegated sandstone, without pebbles (80 to 650 feet).

Like the Permian red rocks below, the sandstones and marls of the Triassic series are almost barren of organic remains. Extraordinary differences in the development of their several members occur, even within the limited area of England, as may be seen from the subjoined table, which shows the variations in thickness from north-west to south-east :—

[1] See P. B. Brodie, *Trans. Geol. Soc.* London, v. (1842), p. 331 ; *Q. J. G. S.* xii. (1856), p. 374 ; xliii. p. 540 ; xlix. (1893), p. 171 ; l. (1894), p. 170. E. Hull, "Permian and Triassic Rocks of England," *Geological Survey Memoirs*, 1869. H. B. Woodward, *Geol. Mag.* 1874, p. 385 ; "Geology of East Somerset and Bristol Coal-fields," *Mem. Geol. Survey*, 1876. Ussher, *Q. J. G. S.* xxxii. p. 367 ; xxxiv. p. 459 ; *Geol. Mag.* 1875, p. 163 ; *Proc. Somerset. Arch. Nat. Hist. Soc.* xxxv. (1889). Etheridge, *Q. J. G. S.* xxvi. p. 174. A. Irving, *Geol. Mag.* 1874, p. 314 ; 1887, p. 309 ; *Q. J. G. S.* 1888, p. 149. W. T. Aveline, *op. cit.* 1877, p. 380. J. G. Goodchild, *Trans. Cumberl. Westmorel. Assoc.* xvii. (1891-92). E. Wilson, *Q. J. G. S.* xliv. (1880), p. 761. T. Tate, *op. cit.* xlviii. (1892), p. 488.

[2] The term "Rhætic" is derived from the Rhætian Alps, where the rocks so named are well developed. "Bunter" and "Keuper" are terms borrowed from Germany, the first was taken by Werner from the variegated (German, *bunt*) colours of the strata, the second is a local miner's term.

		Lancashire and W. Cheshire.	Staffordshire.	Leicestershire and Warwickshire.
		Feet.	Feet.	Feet.
Keuper.	Red marl	3000	800	700
	Lower Keuper sandstone	450	200	150
Bunter.	Upper mottled sandstone	500	50–200	absent
	Pebble-beds	500–750	100–300	0–100
	Lower mottled sandstone	200–500	0–100	absent

Hence we observe that, while towards the north-west the Triassic rocks attain a maximum depth of 5200 feet, they rapidly come down to a fifth or sixth of that thickness as they pass towards the south-east. South-westwards, however, they swell out in Devon and Somerset to probably not less than 2500 or 3000 feet.[1] Recent borings in the south-eastern counties show the Trias to be there generally absent.[2] The main source of supply of the sediment which formed the material of the Triassic deposits probably lay towards the north or north-west. The pebble-beds, besides local materials, contain abundant rolled pebbles of quartz, which have evidently been derived from some previous conglomerate, probably from some of the Old Red Sandstone masses now removed or concealed. The Trias rests with a more or less decided unconformability on the rocks underneath it, so that, although the general physical conditions as regards climate, geography, and sedimentation, which prevailed in the Permian period, still continued, terrestrial movements had, in the meanwhile, taken place, whereby the Permian sediments were generally upraised and exposed to denudation. Hence the Trias rests now on Permian, now on Carboniferous, and sometimes even on Cambrian or Pre-Cambrian rocks. Moreover, the upper parts of the Triassic series overlap the lower, so that the Keuper groups repose successively on Permian and older rocks.

The Bunter series is singularly devoid of organic remains. The rolled fragments in the pebble-beds have yielded fossils at Budleigh Salterton, on the southern coast of Devonshire (where a fine coast-section of the Triassic series is displayed), proving that Silurian and Devonian rocks were exposed within the area from which the materials of these strata were derived. The peculiar quartzites of the Budleigh Salterton pebbles do not seem to have come from any British rocks now visible, but rather to have been derived from the north-west of France.[3] The pebbles in the Bunter conglomerates of the Midlands likewise indicate derivation from some source which has not yet been satisfactorily traced in the British Islands. A marked characteristic of the Bunter series in Central England is its capacity for holding water, whence it is an important source of water-supply.

At the base of the Keuper series, in the region of the Mendip Hills, a remarkable littoral breccia or conglomerate occurs. Over Carboniferous Limestone it consists mainly of limestone, and is precisely like "brockram" (p. 1070), but in the slaty tracts of Devonshire, the fragments are of slate, porphyry, granite, &c. Its matrix being some-

[1] Ussher, *Q. J. Geol. Soc.* xxxii. 392.

[2] Red strata in the deep boring at Richmond are believed by Professor Judd to be Triassic. Mr. Whitaker regards as Trias similar rocks found under Kentish Town and Crossness near London.

[3] For an account of their included fossils see Davidson, *Palæontograph. Soc.* 1881. The nature and origin of the pebbles in the Bunter series of the centre of England have been repeatedly discussed by Professor Bonney. See especially his last paper in *Q. J. G. S.* lvi. (1900), p. 287.

times dolomitic, it has been called the Dolomitic Conglomerate; but it occasionally passes into a magnesian limestone. It represents the shore deposits of the Trias salt-lake or inland sea, and, as it lies on many successive horizons, we see that the conditions for its formation persisted during the subsidence by which the Mendips and other land of this region were gradually depressed and obliterated under the red sandstones and marls (see Figs. 213, 225).[1] The Dolomitic conglomerate averages 20 feet in thickness, but here and there rises into cliffs 40 or 50 feet high. It has yielded two genera of deinosaurs (*Palæosaurus*, *Thecodontosaurus*).[2] Some geologists have regarded this band of rock as an English representative of the German Muschelkalk. But the manner in which it ascends along what was the margin of the Triassic land shows it to be a local base occupying successive horizons in the red rocks. There is no equivalent of the Muschelkalk in Britain, unless the middle division of the Devonshire Trias can be so regarded.[3]

The lower Keuper group is composed of red and white sandstones with occasional lenticular bands of coarser material, and, like the corresponding strata in the Bunter group, is generally unfossiliferous, but has furnished many amphibian footprints. The surfaces of the sandstone-beds are likewise impressed with rain-drops and are marked with desiccation-cracks and ripple-marks, suggestive of flat shores exposed to the air.

In the upper Keuper group the sediments were generally muddy, and now appear as red and variegated marls, with occasional partings of sandstone or bands of dolomite or of gypsum. Among these strata are beds of rock-salt, varying from a few inches to more than 100 feet in thickness. The marly character of the upper Keuper is a distinguishing feature of the group from the south of Scotland to the south of Devonshire, and from Antrim to the east of Yorkshire. Throughout this wide area cubical casts of salt (chloride of sodium) are not infrequent, though this substance is only workable at a few places (Antrim, Cheshire, Middlesbrough).[4] The salt is chiefly obtained by dissolving the material underground and pumping up the brine, very little being now actually mined. The rock-salt as it occurs intercalcated in the marls is a crystalline substance, usually tinged yellow or red from intermixture of clay and peroxide of iron, but is tolerably pure in the best parts of the beds, where the proportion of chloride of sodium is as much as 98 per cent. Through the bright red marls with which the salt is interstratified there run thin seams of rock-salt, also bands of gypsum, somewhat irregular in their mode of occurrence, occasionally reaching a thickness of 40 feet and upwards.

The paucity of organic remains in the English Keuper indicates that the conditions for at least animal life must have been extremely unfavourable in the waters of the ancient Dead Sea wherein these red rocks were accumulated. The land possessed a vegetation which, from the fragments yet known, seems to have consisted in large measure of cypress-like coniferous trees (*Voltzia*, *Walchia*), with calamites on the lower more marshy grounds. The red marl group contains in some of its layers numerous valves of the little crustacean *Estheria minuta*, and a solitary species of lamellibranch, *Tapes?* (*Pullastra*) *arenicolus*. The green gritty marls of Warwickshire have yielded three species of probably marine shells (*Thracia? Pholadomya? Nucula?*), too imperfectly preserved for satisfactory determination.[5] A number of teeth, spines, and sometimes entire skeletons of fish have been obtained (*Dipteronotus cyphus*, *Dictyopyge* (*D. superstes*), *Acrodus keuperinus*, *A. minimus*, &c.). The bones, and still more

[1] De la Beche, *Mem. Geol. Survey*, i. p. 240. H. B. Woodward, "Geology of East Somerset and Bristol Coal-Fields," *Mem. Geol. Survey*, 1876, p. 53.

[2] Etheridge, *Q. J. G. S.* xxvi. p. 174.

[3] Ussher, *op. cit.* xxxiv. p. 469.

[4] T. Hugh Bell on salt deposits of Middlesbrough, *Proc. Cleveland Inst. Engin.* Session 1882-83; and the papers by Mr. Wilson and Mr. Tate cited on p. 1091.

[5] R. B. Newton, *Journ. Conchology*, vii. (1894), p. 408.

frequently the footprints, of labyrinthodont and even of saurian reptiles occur in the Keuper beds—*Labyrinthodon* (4 species), *Cladyodon Lloydii, Hyperodapedon, Palæosaurus, Zanclodon* (*Teratosaurus*), *Thecodontosaurus, Rhynchosaurus,* and footprints of *Cheirotherium.* The remains of *Microlestes* have likewise been discovered in the highest beds sometimes taken as the base of the Rhætic series.

At the top of the Keuper marl certain thin-bedded strata form a gradation upwards into the base of the Jurassic system. As their colours are grey, blue, and black, and contrast with the red and green marls below, they were formerly classed without hesitation in the Jurassic series. Egerton, however, showed that, from the character of the fish remains found in the "bone-bed" of the black shales, they had more palæontological affinity with the Trias than with the Lias. Subsequent research, particularly among the Rhætian Alps and elsewhere on the Continent, brought to light a great series of strata of intermediate characters between the previously recognised Trias and Lias. These results led to renewed examination of the so-called beds of passage in England (Penarth beds),[1] which were found to be truly representative of the massive formations of the Tyrolese and Swiss Alps. They are therefore now known as Rhætic (sometimes as Infra-Lias). In England this subdivision is usually classed as the uppermost member of the Trias, but by some continental geologists it is placed as the base of the Lias. It offers evidence of the gradual approach of the physical geography and characteristic fauna and flora of the Jurassic period.

The Rhætic (Penarth) beds occur as a continuous though thin band at the top of the Trias, throughout the British area. They extend from the coast of Yorkshire across England to Lyme Regis on the Dorsetshire shores.[2] They occur in scattered patches up the west of England, and on both sides of the Bristol Channel, and they have been detected in the west and north of Scotland (p. 1137). Their thickness, on the average, is probably not more than fifty feet, though it rarely increases to 150 feet. In the south-west of England, they consist of the following subdivisions in descending order:—

White Lias—composed of an upper hard limestone (Sun-bed or Jew-stone, 6 to 18 inches) with *Modiola minima* and *Ostrea liassica;* and a lower group of pale limestones (10 to 20 feet) with the same fossils and *Protocardia* (*Cardium*) *phillipiana* (*C. rhæticum*), *Pseudomonotis fallax.* The Cotham Stone or Landscape Marble (4 to 8 inches) is a hard compact limestone, with dendritic markings, lying at the base of these calcareous strata. At Aust it has yielded elytra of Coleoptera, wings of insects, and scales and perfect specimens of the fishes *Legnonotus cothamensis, Pholidophorus Higginsi.*

Black paper-shales (10 to 15 feet), finely laminated and pyritous, with selenite and fibrous calcite ("beef") and one or more seams of ferruginous and micaceous sandstone (bone-bed) containing remains of fish and saurians.[3] Some of the shales yield *Avicula contorta, Protocardia* (*Cardium*) *phillipiana* (*C. rhæticum*), *Pecten valoniensis* (= *Avicula contorta* zone).

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[1] So named from their being well developed in the cliffs of Penarth on the Glamorganshire coast. Bristow, *Brit. Assoc.* 1864, sects. p. 50; *Geol. Surv. Vertical Sections,* sheets 47, 48.

[2] Strickland, *Proc. Geol. Soc.* iii. Part ii. p. 585. H. W. Bristow, *Geol. Mag.* i. (1864), p. 236. T. Wright, *Q. J. G. S.* xvi. p. 374. C. Moore, *op. cit.* xvi. p. 483; xxiii. p. 459; xxxvii. pp. 67, 459. W. B. Dawkins, xx. p. 396. E. B. Tawney, xxii. p. 69. P. B. Brodie, p. 93. F. M. Burton, xxiii. p. 315. W. J. Harrison, xxxii. p. 212. P. M. Duncan, xxiii. p. 12. J. W. Davis, xxxvii. p. 414. E. Wilson, xxxviii. p. 451. H. B. Woodward, "Geology of E. Somerset and Bristol Coal-fields," *Mem. Geol. Survey,* p. 69; *Proc. Geol. Assoc.* x. (1888).

[3] These remains have likewise been found in vast numbers filling fissures in the Carboniferous Limestone which must have communicated with the surface in Rhætic time. One of these fissures in the Mendip Hills yielded twenty-nine teeth of *Microlestes,* nine species of reptiles, and fifteen of fishes, and as many as 70,000 teeth of *Acrodus.* Chas. Moore, *Q. J. G. S.* xxiii. p. 487.

Green and grey Marls (20 to 30 feet), with alabaster, celestine, and sometimes pseudomorphs of rock-salt; generally unfossiliferous, but yielding *Microlestes*. These Marls form properly the top of the Keuper, the bone-bed above serving as a convenient base for the Rhætic beds.

A bone-bed similar to that in the foregoing section reappears on the same horizon in Hanover, Brunswick, and Franconia. Among the reptilian fossils are some precursors of the great forms which distinguished the Jurassic period (*Ichthyosaurus* and *Plesiosaurus*). The fishes include *Acrodus minimus*, *Ceratodus latissimus* (and five other species), *Hybodus minor*, *Nemacanthus monilifer*, &c. Some of the lamellibranchs (Fig. 416) are especially characteristic; such are *Protocardia* (*Cardium*) *phillipiana* (*C. rhæticum*), *Avicula contorta*, *Pecten valoniensis*, and *Tapes?* (*Pullastra*) *arenicola* (Fig. 415).

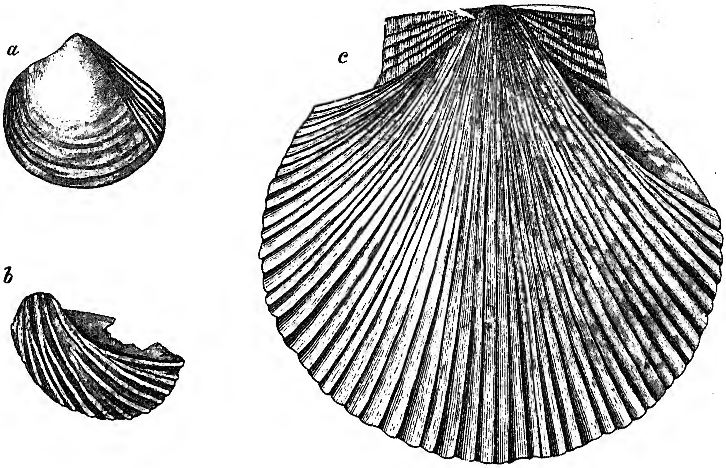

Fig. 416.—Rhætic Fossils.
a, Protocardia phillipiana (Cardium rhæticum, Merian.); *b*, Avicula contorta, Portlock; *c*, Pecten valoniensis, Defrance.

Central Europe.—The lagoon type of the Triassic system, stretching from England by Heligoland (where it is well developed)[1] into Germany, is one of the most compactly distributed geological formations of Europe. Its main area extends as a great basin from Basel down to the plains of Hanover, traversed along its centre by the course of the Rhine, and stretching from the flanks of the old high grounds of Saxony and Bohemia on the east across the Vosges Mountains into France, and across the Moselle to the flanks of the Ardennes. This must have been a great inland sea, out of which the Harz Mountains, and the high grounds of the Eifel, Hunsdrück, and Taunus probably rose as islands. To the westward of it, the Palæozoic area of the north of France and Belgium had been raised up into land.[2] Along the margin of this land, red conglomerates, sandstone, and clays were deposited, which now appear here and there reposing unconformably on the older formations. Traces of what were probably other basins occur eastward in the Carpathian district, in the west and south-east of France, and over the eastern half of the Spanish peninsula. But these areas have been

[1] W. Dames, *Sitzb. Akad. Berlin*, 7th Dec. 1893.

[2] This land, according to MM. Cornet and Briart, rose into peaks 16,000 to 20,000 feet high! (*Ann. Soc. Géol. Nord*, iv.).

considerably obscured, sometimes by dislocation and denudation, sometimes by the overlap of more recent accumulations. In the region between Marseilles and Nice, Triassic rocks cover a considerable area. They contain feeble representatives of the *Grès bigarré* or Bunter beds, and of the *Marnes irisées* or Keuper division, separated by a calcareous zone believed to be the equivalent of the Muschelkalk of Germany. Their highest platform, the Rhætic or *Infra-Lias*, contains a shell-bed abounding in *Avicula contorta*, and is traceable throughout Provence.[1]

In the great German Triassic basin[2] the deposits are as shown in the subjoined table:—

Rhætic or Upper Keuper.

Rhætic (Rhät, Infra-Lias).—Grey sandy clays and fine-grained sandstones, containing *Equisetum*, *Asplenites*, and cycads (*Zamites*, *Pterophyllum*), sometimes forming thin seams of coal. *Protocardia* (*Cardium*) *philippiana* (*C. rhæticum*), *Avicula contorta*, *Estheria minuta*, *Nothosaurus*, *Trematosaurus*, *Belodon*, and *Microlestes antiquus*.[3]

Keuper.

Keupermergel, Gypskeuper.—Bright red, green and mottled marls, with an underlying set of beds of gypsum and rock-salt. In some places where sandstones appear, they contain numerous plants (*Equisetum columnare*, *Pterophyllum*, &c.), and labyrinthodont and fish remains[4] (300 to 1000 feet).

Lettenkohle, Kohlenkeuper.[5]—Grey sandstones and dark marls and clays, with abundant plants, sometimes forming thin seams of an earthy hardly workable coal (Lettenkohle), about 230 feet. The plants include, beside those above mentioned, the conifers *Araucarioxylon thuringicum*, *Voltzia heterophylla*, *Widdringtonites keuperianus*, *Tæniopteris vittata*, *Pterophyllum longifolium*, &c. A few shells have been obtained from this group, especially from a band of dolomite at its upper limit (*Lingula tenuissima*,

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[1] Hébert, *Bull. Soc. Géol. France* (2e sér.) xix. p. 100. Dieulafait, *Ann. Sci. Géol.* i. p. 337.

[2] E. Weiss, *Neues Jahrb.* 1869, p. 215; *Z. D. G. G.* xxi. (1869), p. 837. C. W. Gümbel, 'Geognostische Beschreibung des Königreichs Bayern,' iii. (1879), chap. xv. F. Roemer, 'Geologie von Oberschlesien,' 1870, p. 122. E. W. Benecke, 'Über die Trias in Elsass-Lothringen und Luxemburg,' *Abh. Geol. Specialkarte Elsass-Loth.* i. Part iv. (1877). G. Meyer, *Mitth. Com. Geol. Els.-Loth.* i. Part i. (1886). H. Bucking and E. Schumacher, *op. cit.* ii. Part ii. (1889). E. W. Benecke and L. van Werveke, *op. cit.* iii. Part i. (1890). A. Steuer, *op. cit.* iv. (1896); and papers by E. E. Schmid, M. Bauer, W. Frantzen, J. G. Bornemann, A. von Koenen, H. Loretz, H. Grebe, H. Proescholdt and G. Müller in the volumes of the Jahrbuch of the Prussian Geological Survey. Detailed measured sections of the Muschelkalk and Lettenkohle in Franconia are given by F. v. Sandberger, *Verh. Phys. Med. Ges. Würzburg*, xxvi. (1892) No 7. S. Passarge, 'Das Roth im östlichen Thüringien,' Jena, 1891. E. A. Wülfing, *Jahresheft Verein. Vaterland. Naturkund. Württemberg*, lvi. (1900), pp. 1-46.

[3] The *Avicula contorta* zone (see Dr. A. von Ditmarr, 'Die Contorta-Zone,' Munich, 1864) ranges from the Carpathians to the north of Ireland and from Sweden to the hills of Lombardy. In northern and western Europe, it forms part of a thin littoral or shallow-water formation, which over the region of the Alps expands into a massive calcareous series, that accumulated in a deeper and clearer sea. It is well developed also in northern Italy. See Stoppani, 'Géologie et Paléontologie des Couches à Avicula Contorta en Lombardie,' Milan, 1881.

[4] It is deserving of notice that while in the pelagic or Alpine facies of the European Trias fish-remains are on the whole scarce, and only occur in numbers at a few places, they are widely distributed and tolerably abundant throughout the German Trias. See O. Jaekel, *Abhand. Geol. Specialkart. Elsass-Lothr.* iii. Heft iv. (1889).

[5] On the lithological subdivisions of the Muschelkalk and Lettenkohle groups see Professor Sandberger's paper above cited. The Lower Keuper of Eastern Thuringia is described by E. E. Schmid, *Abhandl. Preuss. Geol. Landesanst.* i. Heft ii.

M[illegible], *M. transversa*, *Anoplophora*, *Hœrnesia socialis*, [illegible]. Some of the shales are crowded with small phyllopod [illegible] *E*[illegible], also *Baiadia*). Remains of fish (*Acrodus*, *H*[illegible]) and of the *Mastodonsaurus Jægeri* and *Nothosaurus* have [illegible] from one or two bone-beds in the group.

Upper [illegible] (Hauptmuschelkalk), divisible in Thuringia into two groups, [illegible] limestone (Trochitenkalk) and an upper group of [illegible] with argillaceous partings, known as the Nodosus group [illegible] *Ceratites nodosus*, 200 to 400 feet). In some regions [illegible] still higher group of dolomites and limestones, 6 feet [illegible] the Trigonus group from the prevalence in it of *Trigonodus* [illegible]. The upper Muschelkalk is by far the most abundantly fossiliferous [illegible] of the German Trias. Among its fossils, *Temnocheilus* [illegible], *Ptychites dux*, *Ceratites antecedens*, *C. trinodosus*, *[illegible]*, *M*[illegible] *vulgaris*, *Trigonodus Sandbergeri*, and *Terebratula* [illegible] are specially characteristic, with *Encrinus liliiformis* in the [illegible] and *Ceratites nodosus* in the upper part of the rock. Some [illegible] of the lower limestones are almost wholly made up of crinoid stems.

Middle [illegible] Anhydrite, consisting of dolomites with anhydrite, [illegible] salt. Nearly devoid of organic remains, though bones [illegible] have been found (100 to 300 feet).

Lower [illegible] (Wellenkalk), consisting of limestones and dolomites [illegible], with in the upper part bands of porous limestone known as [illegible] (100 to 300 feet). This zone is on the whole poor in fossils, save in the limestone bands, some of which are full of *Encrinus* [illegible], *E. [illegible]*, *E. Carnalli*, *Pecten lævigatus*, *Hœrnesia* [illegible], *M*[illegible]. The middle portion of the limestone has yielded a number of brachiopods (*Spiriferina fragilis*, *S. hirsuta*, *Athyris* [illegible], *T*[illegible], *T. angusta*), while the upper part or Schaumkalk contains numerous lamellibranchs, especially the widespread genus *Myophoria* (*M. vulgaris*, *orbicularis*, *elegans*, *cardissoides*), *Gervillia* [illegible], *M*[illegible] *Alberti*, *Pecten discites*, *Dentalium torquatum*, and some ammonites (*Beneckeia Buchi*, *Hungarites Strombecki*, *Balatonites Ottonis*, [illegible]).

Upper (Röth). Red and green marls, with gypsum in the lower part, and sometimes [illegible] rock-salt (250 to 300 feet). Occasional bands of dolomite [illegible] dolomite of Thuringia yield a number of fossils (*Rh*[illegible], probably a sponge, *Myophoria costata*, *M. vulgaris*, *H*[illegible], the ammonite *Beneckeia tenuis*). The *My*[illegible] characteristic. The plants of this stage consist [illegible], with ferns and horse-tails.

Middle. Coarse-grained sandstones (1000 feet), sometimes incoherent, with [illegible] of *Estheria* shale; amphibian footprints and remains of labyrinthodonts.

Lower. [illegible] false-bedded sandstone (Grès des Vosges) several hundred feet thick, often micaceous and friable, with occasional [illegible] of dolomite and of the marly oolitic limestone called "Rogenstein." Fossils extremely scarce; *Estheria minuta* occurs in some layers.

The Bunter [illegible], in the north and centre of Germany, lies conformably on and passes insensibly into the Zechstein. Except in the dolomite beds of the Röth, it is usually barren of organic remains. The plants already known include *Equisetum* [illegible], *E. Mougeoti*, one or two ferns (*Anomopteris*, [illegible]), and a few conifers (*Albertia* and *Voltzia*). The lamellibranch *Myophoria costata* is found in the upper division all over Germany. Numerous footprints (*Cheirotherium*, Figs. 211, 212) occur on the sandstones, and the bones of labyrinthodonts (*Trematosaurus*, *Capitosaurus*) as well as of fish have been obtained.

In the Vosges, the Bunter (Grès bigarré, Vosgian) consists of (1) a lower coarse red unfossiliferous sandstone (Grès des Vosges) resting conformably on the red Permian sandstone and marked by the frequent crystalline condition of its quartz-grains (crystallised sandstone, p. [illegible]), also by its quartz-conglomerates, which occasionally reach a

thickness of more that 1600 feet; (2) an upper series of red sandstones, surmounted by marls, forming the *Grès bigarré* and containing among other fossils *Voltzia*, *Albertia*, *Equisetum arenaceum*, *Myophoria*, *Nothosaurus Schimperi*, *Menodon plicatus*, *Odontosaurus Voltzii*, *Mastodonsaurus vaslenensis*. The Muschelkalk in the same region is a compact grey limestone capable of subdivision into three zones, as in Germany, while the Keuper (Marnes irisées) presents a characteristic assemblage of bright red and green mottled argillaceous marls.[1]

Spanish Peninsula.—The lagoon type of the Trias extends southwards into the eastern part of the Pyrenees and through the east and south of Spain. In the district around Molina de Aragon the three German subdivisions of the system have been recognised.[2] The lower conglomerates and sandstones of the province contain land plants (*Equisetum*, *Albertia*). Higher horizons in different parts of the peninsula present marls and dolomites sometimes with Muschelkalk fossils. In the Pyrenees also various saliferous marls occur which are assigned to this system.

Scandinavia.[3]—Northwards the Triassic lagoons of Central Europe stretched as far as Sweden. Though fragmentary remains of the terrestrial flora that clothed the land which surrounded the German Triassic inland sea not infrequently occur in the deposits of that basin, it is towards the north that the most abundant traces have been recovered of the vegetation of the period. Above reddish saliferous rocks, presumably Triassic, there come in southern Sweden certain light grey and yellow strata, which, from the occurrence of *Avicula contorta* and other fossils in them, are assigned to the Rhætic stage, though possibly their higher members may be Jurassic. They attain in some places a thickness of 500 to 800 feet, and cover about 250 square miles. They have been divided into a lower fresh-water group, with workable coal seams, but no marine fossils, and an upper marine group, with only poor coals, but with numerous marine organisms (*Ostrea*, *Pecten*, *Avicula*, &c.). In the coal-bearing strata clay-ironstones occur, and seams of fireclay underlie the coals. Nathorst and Lundgren have brought to light 150 species of plants from these beds—a larger number than the whole of the Triassic flora of the rest of Europe. At Bjuf they include 36 species of ferns, 36 cycads, 15 conifers, and 1 monocotyledon. The Swedish Triassic rocks have been arranged as follows:—

Younger Rhætic	Base of Lias with *Cardinia*, &c. Zone of *Nilssonia polymorpha*.
Middle Rhætic	"Pullastra" bed. (*Tapes?* [*Pullastra*] *elongatus*, *Mytilus minutus*, *Ostrea Hisingeri*.) Zone of *Thaumatopteris Schenki*. Zone of *Equisetum gracile*, *Podozamites lanceolatus*.
Older Rhætic	Zone of *Lepidopteris Ottonis*. Zone of *Camptopteris spiralis*, *Baiera paucipartita*. Zone of *Anomozamites gracilis*, *Palissya Sternbergi*, *Dictyophyllum exile*.

Alpine Trias.[4]—We now pass to the consideration of the pelagic or open sea

[1] Benecke, *Abhandl. Specialkart. Elsass-Lothringen*, 1877; Lepsius, *Z. D. G. G.* 1875, p. 83; and his 'Geologie von Deutschland.'

[2] D. Salvador Calderón, *An. Soc. Esp. Hist. Nat.* xxvii. (1898), p. 177.

[3] See Hébert, *Ann. Sci. Géol.* 1869, No. 1; *B. S. G. F.* (2), xxvii. (1870), p. 366. *Memoirs of the Geological Survey of Sweden*, especially Nathorst "Om Floran Skånes Kolförande Bildningar," 1878, 1879; E. Erdmann, "Beskrifning till Kartbladet Helsingborg," 1881, p. 42; G. Lindström, "Kartbladet Engelholm," 1880; also Nathorst, "Bidrag till Sveriges fossila Flora," *K. Vet. Akad. Handl. Stockholm*, xiv. xvi.; *Neues Jahrb.* 1876, pp. 105, 891; 1879, pp. 973, 1004; (1882), i. p. 70. Lundgren, *Geol. Fören. Stockholm Förh.* 1880; *Ann. Geol. Univ. Lund.* iv.

[4] See F. von Richthofen, 'Geognostische Beschreibung der Umgegend von Predazzo,' &c. Gotha, 1860. Gümbel, 'Geog. Beschreib. des Bayerisch. Alpen,' 1861. Stur, 'Geologie der

development of the European Trias which extends across the Mediterranean basin. In the western Alps, certain lustrous schists, with gypsum, anhydrite, dolomite, and rock-salt, lie underneath the Jurassic series, and have been referred to various geological horizons. Some part of them undoubtedly belongs to the Trias.[1] On the Italian side, they swell out to great proportions, reaching a thickness of more than 13,000 feet along the line of the Mont Cenis Tunnel. Traced through Piedmont, they are found to play an important part in the structure of the northern Apennines, where they contain the celebrated statuary marbles of Carrara (pp. 804, 1105). They have undergone, in these mountainous tracts, extensive metamorphism, the original shales or marls being changed into lustrous schists, and the limestones into crystalline marbles. But even in this altered condition Triassic fossils have been found in them.

Already in Triassic time a notable distinction had been established between the geographical conditions of the regions now marked by the eastern and western Alps. The line of division between the two areas may be said to coincide generally with that ancient line of N.E. and S.W. disturbance known as the "Rhine-Ticino fault." To the west the Triassic deposits point to varying conditions of lagoons and inland seas. Eastward, however, the corresponding deposits attain an enormous development, and are now recognised as presenting a record of the deeper water or pelagic conditions of the Triassic period. As Mojsisovics has remarked, what England and North America are for the Palæozoic formations in general, what Bohemia is for the Silurian system, what the Jura Mountains are for the Jurassic deposits, the eastern Alps are for the Trias.[2] Special interest attaches to the Trias of these Alps from the great thickness of its limestones and their thoroughly marine fauna, with a commingling of Palæozoic and Mesozoic types intercalated between the Permian and Jurassic systems. It would appear that during the deposition of these limestones the central core of crystalline and Palæozoic rocks of the Alpine chain rose as an island that stretched from the Engadine eastward into Austria. North of this old insular tract the Triassic strata are on the whole somewhat sandy, the accumulation of limestone there having been frequently interrupted by inroads of sand or silt. On the south side the deposition of limestone and dolomite went on more continuously, though interfered with occasionally by submarine volcanic eruptions. Some of the dolomite masses may have been coral-reefs; Mojsisovics even believes that in the conglomeratic portions he can detect traces of the breaker-action by which the reefs were ground down, while the thin marls were deposited in lagoons, or in the inner channels between the reefs and the land. But it is specially

Steiermark,' 1871. E. von Mojsisovics, *Jahrb. Geol. Reichsanstalt*, Vienna, 1869, 1874, 1875, 1880; *Abhandl. Geol. Reichsanstalt*, 1875-1893; *Verhandl. Geol. Reichsanstalt*, 1866, 1875, 1879, 1896; *Sitzb. Akad. Wien*, ci. (1892), p. 769; cv. (1896), p. 5; and 'Dolomitriffe Südtirols und Venetiens,' 1878. E. Suess, 'Die Enstehung der Alpen,' 1875. Memoirs by Von Hauer, Laube, Suess, Stache, Stur, Toula, Bittner, and others in the *Jahrb. Geol. Reichsanstalt.* Von Hauer's 'Geologie,' p. 358 *et seq.* Mrs. Gordon (Miss M. Ogilvie), *Q. J. G. S.* xlix. (1893), p. 1; *Geol. Mag.* 1892, p. 145; 1894, p. 355; 1900, p. 337; *Verhandl. Geol. Reichsanst.* 1900, p. 306. The fossils are described by Benecke, *Geol. Palæontol. Beitr.* vol. ii.; Mojsisovics, *Abhandl. Geol. Reichsanst.* vi. vii. x.; *Palæontologia Indica*, ser. xv. vol. iii. (1899); G. L. Laube, *Denksch. Akad. Wien*, xxiv.-xxx.; A. Rothpletz, *Palæontographica*, xxxiii. (1886), pp. 1-180. Numerous other memoirs are cited by Mojsisovics in his 'Dolomitriffe.'

[1] The "Schistes lustrés" of the western Alps and the "Bündnerschiefer" farther east have given rise to much discussion (p. 802). The controversy has been well summarised by Professor J. W. Gregory, *Q. J. G. S.* lii. (1896), and by Professor Rothpletz, *Z. D. G. G.* 1895, Heft i. There can be little doubt that these rocks consist of a great series of altered strata, which include Archæan, Palæozoic, Mesozoic, and even perhaps Cainozoic formations. The Triassic portion of them is generally recognisable by its peculiar lithological characters.

[2] 'Die Dolomitriffe,' p. 39.

deserving of notice that corals were not the only agents in the accumulation of reef-like masses in this region. Alike in the dolomites and the massive limestones calcareous sea-algæ occur so abundantly as to show that they grew up into wide reefs, which, judging from what is known of the distribution of such organisms at present, show that the Triassic sea in these tracts did not exceed 200 fathoms in depth. Though organisms of higher grade are often associated with these reef-building plants, they occur most frequently in the thin-bedded marls and shales at definite horizons in the series of strata.

Having regard to the lithology and palæontology of the Alpine Trias, Mojsisovics proposed some years ago to consider the system in the eastern Alps as pointing to the existence of two great marine "provinces." The larger of these lay over the sites of North and South Tyrol, Lombardy, and Carinthia, and stretched far to the east. To this area the able Austrian investigator gave the name of the "Mediterranean province." To the other, which occupied a limited tract on the north-east slopes of the Austrian Alps, extending from the Salzkammergut into Hungary, he gave the designation of "Juvavian province" (from the old Roman name of Salzburg). Though the Triassic deposits of these two regions were geologically contemporaneous, they enclose remarkably different assemblages of organic remains, insomuch that the palæontological zones which can be determined in the one have not been found to hold good in the other. In no respect is this independence more strongly shown than in the great contrast presented by the Ammonites of the two areas. The Juvavian province has yielded a Triassic cephalopodous fauna far outrivalling in variety and interest that of any other tract. It was for a long time believed that the cephalopods were quite distinct in the two regions, *Phylloceras*, *Didymites*, *Halorites*, *Tropites*, *Rhabdoceras*, and *Cochloceras* being regarded as the dominant and distinctive genera of the Juvavian province, while *Lytoceras*, *Sageceras*, and *Ptychites* were equally characteristic of the Mediterranean province.[1] The progress of research, however, has shown that the so-called Juvavian province can no longer be strictly maintained, for the type of rocks and fossils on which it was based have been found in the midst of the Mediterranean basin. Nevertheless it remains true that the peculiar lithological and palæontological features, as well as the complicated structure, of the district of the Salzkammergut have up to the present time interposed very great difficulties in the way of the institution of any exact comparison between the Triassic succession in that area and in other parts of the Alpine region. The table on the following page, compiled from the results of recent researches, shows the contrasted grouping of the Triassic formations on the two sides of the eastern Alps, and their distinction from those of the German inland sea, between which and the Alpine basins there seem to have been only occasional and brief intervals of connection:[2]—

[1] Mojsisovics has modified his earlier opinions regarding the order of the Triassic formations in the Salzkammergut (*Sitzb. Akad. Wien*, 1892, p. 780).

[2] In the preparation of this account of the Alpine Trias I was greatly aided by Mrs. Gordon, whose intimate acquaintance with this geological system in the eastern Alps is well shown in her papers already cited. The table on next page was entirely drawn up by her. Compare the Table on p. 1106.

German Trias.[1]		Stages according to Mojsisovics.	Alpine Fossil Zones.	In the Northern Alps. Bavarian and North Tyrol.	In the Northern Alps. Upper and Lower Austria.	In the Southern Alps. Lombardy Alps.	In the Southern Alps. Carinthian Alps and S. Tyrol.	
Rhætic beds.		Rhætic. Stage.	1. *Megalodon scutatus* and *Avicula contorta*.	Dachstein Limestone. Kössen beds. (Dachstein and Coral-reef Limestone.)	Dachstein Limestone or Kössen beds.	Kössen beds (Arzzarola beds).	Dachstein Dolomite.	
		Juvavian Stage.	2. *Turbo solitarius* and *Avicula exilis*.	Main Dolomite. (Dachstein and Coral-reef Limestone.)	Dachstein Limestone or Dolomite. (Hallstadt (Salzkammergut) development of limestones, dolomites, &c., with lenticular fossiliferous intercalations.)	Main Dolomite.		
Keuper.	Upper or Gypskeuper. Lower Keuper. (Lettenkohle).	Carinthian Stage.	3. *Trachyceras aonoides*.	Raibl beds. { "Ostrea" horizon. "Cardita crenata" horizon.	Opponitz Limestone. Lunz Sandstone.	Raibl beds (Gorno and Dossena beds).	Raibl beds. { Torer beds Dolomite. Fischschiefer.	Raibl beds.
Muschelkalk.	Upper and Middle Limestones.	Carinthian Stage.	4. *Trachyceras aon*.	Wetterstein Limestone. (Wetterstein or Reef Limestone.)	Partnach beds.	Esino Limestone.	"Erzfuhrende Dolomit" of Raibl. Cassian beds.	Schlern Dolomite.
		Noric Stage.	5. *Trachyceras Archelaus* and *Halobia Lommeli*.	Partnach beds. (Wetterstein or Reef Limestone.)				
		Noric Stage.	6. *Trachyceras Curionii*.		Reifling Limestone.	"Halobia" Shales or Prezzo Limestones.	Wengen Beds. Buchenstein beds.	
	Lower Limestones (Wellenkalk).		7. *Ceratites trinodosus*.	Alpine Muschelkalk.	Guttenstein Limestone.	Muschelkalk (Recoaro Limestone).	Muschelkalk (Virgloria Limestone).	Mendola Dolomite.
			8. *Ceratites binodosus* and *Terebratula vulgaris*.					
Bunter.	Röth horizon. Middle and Lower Buntsandstones.		9. *Myophoria costata* and *Tirolites cassianus*.	"Myophoria" beds or Reichenhall Limestone with beds of salt, gypsum, &c. Werfen beds.		Röth Werfen beds.	Werfen beds. { Campil beds. Seis beds.	

[1] For a comparison between the Trias of Germany and that of the Alps, see Wöhrmann, *Jahrb. k. k. Geol. Reichsanst.* 1889, p. 181. A useful summary will be found in Fraas' 'Scenerie der Alpen,' p. 146.

1. Bunter.—The base of the Alpine Trias shades down into the Permian formations (Bellerophon limestone, Gröden sandstone), and consists of the group of red sandy micaceous shales known as the Werfen beds (from Werfen in the Salzburg), which form a tolerably persistent horizon. Among the fossils in the upper part are *Naticella costata, Turbo rectecostatus, Myophoria costata, Monotis aurita*, and the ammonites *Tirolites (Ceratites) cassianus, Dalmatinus idrianus, D. muchianus, Trachyceras Liccanum, Norites caprilensis.* Some of these organisms occur so abundantly as to form entire beds. Corals, echinoderms, and brachiopods (except *Lingula*) are absent. In the lower part of the group *Monotis Clarai* is especially abundant. The presence here of *Myophoria costata*, a characteristic form of the German Röth, serves to mark the relation of the Werfen beds to the Triassic series of the German area.

2. Muschelkalk.—It is above the position of the Werfen beds that the Alpine Trias begins to manifest great lithological differences, not only in the two provinces on the northern and southern sides of the Alps, but even within the confines of each province The general character of these differences is expressed in the foregoing table. Yet, with some notable exceptions, the palæontological zones can be distinguished. The lower Muschelkalk of the eastern Alps consists in its inferior portion of sedimentary deposits which are largely argillaceous, while the upper part is composed of limestones and dolomites arranged in lenticular reef-like masses. The lower argillaceous division varies in its palæontological character. Mojsisovics distinguishes three facies, the lowest in which lamellibranchs predominate (Recoaro), and which shows a close lithological and palæontological relation to the German Muschelkalk, followed by one with brachiopods and land-plants, and that by a third with cephalopods (Dont, Val Inferna and Brags). The calcareous group sometimes resembles in lithological character the German Wellenkalk, but in certain places it assumes the aspect of reefs. Among the most important fossils of the Alpine Lower Muschelkalk some are common to this stage in Germany, such as *Spiriferina Mentzeli, S. hirsuta, Rhynchonella decurtata, Terebratula (Cœnothyris) vulgaris, T. angusta, Myophoria vulgaris, Pecten discites, Encrinus gracilis, Ceratites trinodosus.* But there remains a large number of peculiar forms, especially the abundant ammonites (*Ptychites, Trachyceras*, numerous species, *Lytoceras*). The Upper Muschelkalk is generally a dark grey to black limestone, but sometimes (Salzkammergut) is red and like a marble. Among the typical fossils are *Halobia (Daonella) Sturi, H. (D.) parthanensis, Orthoceras campanile, Nautilus Pichleri, Ptychites gibbus, Arcestes Bramantei, Ægoceras megalodiscus, Ceratites (Trachyceras) trinodosus*, and others.

3. Noric Stage.—It was at the close of the deposition of the Alpine Muschelkalk and the beginning of the Noric stage that the two great biological provinces above referred to were finally established. The general grouping of the formations in each area and the striking difference they present even within the same area are best understood from the inspection of such a table as that given above. On the southern side of the Alps two groups in this stage have been recognised: (1) the Buchenstein beds, consisting of flaggy and nodular limestones, with hornstone concretions. These strata have not yet been found in the northern Alps. Among their fossils are *Orthoceras Böckhi, Arcestes trompianus*, and other species, *Ptychites angusto-umbilicatus, Sageceras Zsigmondyi, Lytoceras, cf. wengenense, Trachyceras Curionii, T. Reitzi*, and other species, *Spiriferina Mentzeli, Halobia (Daonella) Taramellii*, and other species. (2) The Wengen beds comprise all the strata lying between the Buchenstein beds and the base of the St. Cassian group. Their most important material consists of a dark sandstone with shaly partings, derived chiefly from volcanic detritus. In South Tyrol and in Carinthia sheets of lava and tuff lie at the base of this group, and thicken out round the centres of eruption. With these interbedded igneous rocks are associated bosses and dykes of augite-porphyry and melaphyre. A characteristic feature of the Wengen beds is the great development of reefs formed by calcareous algæ (*Gyroporella*, including *Diplopora*), and built up into enormous masses of limestone and dolomite with corals, large Naticas, and Chemnitzias. Among the characteristic fossils of the Wengen beds are *Trachyceras Archelaus*, and

numerous other species, *Arcestes tridentinus*, *Pinacoceras daonicum*, *Halobia Lommeli*, with in some places remains of land-plants, which include *Equisetites arenaceus*, *Neuropteris* several species, *Sagenopteris*, *Pecopteris*, *Thinnfeldia*, *Pterophyllum*, *Tæniopteris*, *Voltzia*.[1]

4. Carinthian Stage.—The geographical distribution of the two marine provinces lasted beyond the early part of this stage. Thereafter the separation between them gradually disappeared, and some of their peculiar ammonites began to migrate from the one territory to the other. In the southern area Mojsisovics has noted three distinct Carinthian groups: (1) the St. Cassian beds, consisting of brownish calcareous marls, limestones, and oolites. This group has long been celebrated for the astonishing abundance and variety of its organic remains. The Echinoderms are particularly prominent. Abundant also are the species of *Halobia* (*Daonella*) (*H. cassiana* and *H. Richthofeni*). Corals abound in the neighbourhood of the dolomite-reefs, and the coral banks, like the beds of echinoderms, can be traced laterally into these reefs. The St. Cassian beds are represented in other parts of the Alps by fossiliferous limestones (Marmolata and Esino limestones in South Tyrol and Lombardy, Wetterstein limestone in North Tyrol) and nearly unfossiliferous dolomites (Schlern dolomite in South Tyrol, "Erzführende Dolomit" of Carinthia) of the "reef-type" of Mojsisovics. Out of the large series of fossils the following may be mentioned here:—*Trachyceras aon*, species of *Arcestes*, *Lobites*, *Orthoceras*, *Nautilus*, *Bactrites*, *Gervillia angusta*, *Koninckina Leonhardi*, *Rhynchonella semiplecta*, *Encrinus cassianus*, *Pentacrinus propinquus*, *Cidaris dorsata*. (2) The Raibl beds[2] mark the close of the separation of the two provinces, for they range from the one into the other. They consist of dark bituminous marly strata, with lenticular beds and thick reef-like masses of limestone, and frequently with gypsum and rauchwacke. Their fauna, distinguished by the large number of littoral lamellibranchs, includes *Trigonia Kefersteini*, *Cardita Gümbeli*, *Corbula Rosthorni*, *Halobia rugosa*, *Gervillia bipartita*, *Megalodus carinthiacus*, *Chemnitzia eximia*, *Nautilus Wulfeni*, *Trachyceras aonoides*. The Lunz sandstones, which belong to this horizon, have yielded numerous land-plants comprising many species of *Pterophyllum* and forms of *Equisetites*, *Calamites*, *Neuropteris*, *Alethopteris*, &c. (3) The beds comprising the zone of *Avicula exilis* and *Turbo solitarius* show a return of the dolomitic condition of earlier parts of the system. These conditions had already set in during the deposition of the Raibl beds, but they reached their full development during the accumulation of the next group, when masses of dolomite ranging up to nearly 4000 feet in thickness were laid down. This group of rocks, though placed by Mojsisovics in the Carinthian stage, is by other authors considered to be Rhætic. In North Tyrol it is known as the Main Dolomite (Hauptdolomit), in the Salzkammergut as the lower part of the Dachstein limestone, which forms an important feature in the scenery of the district. These rocks everywhere present a great contrast to the strata below them in their poverty of organic remains. Some of their most prominent fossils are casts of *Megalodus* (*M. Gümbeli*, *M. complanatus*, *M. Mojsvári*, &c.), and remains of calcareous algæ (*Gyroporella*). The bituminous Seefield beds of the North Tyrol have yielded many fishes (*Semionotus*, *Lepidotus*, *Pholidophorus*) and remains of plants.

Until recently, according to Mojsisovics, the order of superposition of the rocks in the Hallstadt area was misinterpreted. He now believes that the Hallstadt marble does not form a continuous mass overlying the Zlambach beds, but that the latter, instead of underlying the Hallstadt rock, actually lie within it. He has grouped a section of the Hallstadt series as a separate stage under the name of "Juvavian." It consists at the base of red and variegated lenticular seams of limestone with *Sagenites Giebeli*. Then follow red lenticular limestones with gasteropods (zone of *Cladiscites*

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[1] On the Wengen, St. Cassian, and Raibl groups of the Seiser Alp, Tyrol, see K. A. von Zittel, *Sitzb. Bayer. Akad.* Munich, xxix. (1899), p. 341. On the fossils of the Wengen and Cassian groups, see Mrs. Gordon, *Q. J. G. S.* xlix. (1893), pp. 1-78; *Geol. Mag.* 1900, p. 337.

[2] Freih. v. Wöhrmann, "Die Raibler Schichten," *Jahrb. Geol. Reichsanst*, 1893, p. 617.

ruber). It is here that the Zlambach beds come in with their *Choristoceras Haueri*. They are succeeded by grey limestone with *Pinacoceras Metternichi*, and this by seams of limestone carrying *Cyrtopleurites bicrenatus*.[1] This whole series, comprising several palæontological zones, is regarded by Mojsisovics as the equivalent in time of the Main Dolomite.

5. Rhætic Stage.—Two distinct facies of this stage are developed in the eastern Alps, but the unity of the deposits over the whole region is shown by the presence of the characteristic *Avicula contorta*. The Kössen beds are a marly, highly fossiliferous group of strata, marking probably the shallower water, while the upper Dachstein limestone into which they merge may indicate the opener sea. Suess has distinguished a series of "facies" in this group, the lowest (Swabian) marked by the preponderance of lamellibranchs, the next (Carpathian) by the abundance of *Terebratula gregaria* and *Plicatula intusstriata*; the Hauptlithodendron-limestone—a thick mass of coral limestone; the Kössen facies including the dark brachiopod limestones with shaly partings, and the Salzburg facies recognisable by the prominence of its cephalopods (*Choristoceras Marshi*, *Ægoceras planorboides*).

The Kössen beds are most fully developed in the northern Alps, more particularly in Bavaria and North Tyrol, thinning out towards Salzkammergut, while the dolomitic facies of Dachstein limestone predominates in the southern Alps, the fossiliferous marly facies only appearing in the Lombardy Alps. The occurrence of the fossiliferous Rhætic beds in the Alps gave not only the first clue to the identity in time of the Triassic beds in Alpine and extra-Alpine regions, but it has proved of the greatest importance in tracing the zonal parallelism of the Triassic succession within the Alps themselves. As has been said, a great thickness of wholly unfossiliferous dolomitic and gypsiferous rock sometimes occurs in the western Alps, and it would be impossible to assign a Triassic age to any part of this series were it not for the presence of well-known Rhætic fossils in the beds immediately succeeding them. Again, the same fossils give undoubted evidence of the gradual submersion of the island of older crystalline and Palæozoic rocks in the Triassic sea of the eastern Alps. Rhætic fossils are found on the Radstädter Tauer and on the Stubey Mountains in the central chain of the Alps.

The intrusive volcanic rocks of the celebrated districts of Predazzo and Monzoni in South Tyrol are referred by some authors to Lower, by others to Upper Triassic time. At Predazzo there is a core of orthoclase porphyry and tourmaline granite with an envelope of syenite, by which, among the now familiar phenomena of contact-meta morphism, the Triassic limestones have been in places converted into marble. Similar phenomena are presented at Monzoni, where a central boss of augite-syenite, traversed by veins of gabbro, melaphyre, &c., cuts across the Triassic strata (*ante*, p. 774).

The Triassic rocks of the Alps have participated in the great earth-movements to which this chain of mountains owes its structure, and they consequently present remarkable cases of dislocation, inversion, and even of metamorphism. Thus the Triassic formations of the Radstädter Tauer in the Tyrol cannot be separated from the calc-mica schist of that district, and Professor Suess regards this schist as an altered Triassic limestone.[2]

Mediterranean Basin.—Continued study of the pelagic facies of the Trias as first encountered in the eastern Alps has shown that this type extends throughout the Mediterranean basin, extending into Asia Minor and sweeping across central and southern Asia even as far as Japan and the East Indian Archipelago. On the borders of the Mediterranean enough has been ascertained to show how widely the open Triassic sea spread over that region. On the west side, Lower (Dinarian) and Upper (Noric) Triassic cephalopods have been obtained from the district of Barcelona.[3] The Balearic

[1] Mojsisovics, *Sitzb. Akad. Wien*, 1892, p. 769.

[2] *Anzeiger Akad. Wien*, No. xxiv. 20th Nov. 1890.

[3] Mojsisovics, *Sitzb. Akad. Wien*, civ. pp. 1295, 1299.

Isles have furnished fossils indicating the presence of Lower Noric (Fassanian) strata. In the north of Italy Triassic formations, sometimes in a much altered condition, have been detected in the Cottian and Apuan Alps. The famous statuary marbles of Carrara, as already mentioned (p. 804), are regarded as probably part of this metamorphosed series. Right down the centre of the peninsula Triassic rocks appear here and there in the axes of the deeper folds into which the Jurassic, Cretaceous, and Tertiary rocks of the Apennine chain have been thrown. Near the south end of the Peninsula they form lofty ranges of hills which, as at Monte Papa, rise more than 6000 feet above the sea, and in that district they have supplied upper Triassic (Longobardian) shells.[1] They reappear in Sicily and again on the east side of the Adriatic, where they range through Dalmatia. In the island of Crete, phyllitic limestones, gypsum, dolomite, black slates, and quartzites containing recognisable fossils have been referred to the Upper Trias. But they have undergone great metamorphism, the altered limestones hardly differing from the most ancient varieties, while the cipollinos have become coarsely crystalline.[2] Lower Trias fossils have been obtained from many places in Bosnia. The system rises once more on the farther side of the Hungarian plain, and stretches through the Carpathian chain by the Bukovina into the Dobrudscha.

The prolonged examination of the remarkably fossiliferous deposits of Hindustan has supplied some gaps that occur in the European development of the Triassic system, and has led the Austrian geologists to a revision and readjustment of the classification and equivalents of the various formations, as shown in the accompanying table:[3]—

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[1] G. de Lorenzo, *Atti. Accad. Napoli.* vi. ser. 2, No. 15 (1894), p. 50; vii. No. 8 (1895). Baldacci and Viola, *Boll. Com. Geol. Ital.* xxv. (1894), p. 372. G. di Stefano, xxvi. (1896), p. 4.

[2] L. Cayeux, *Compt. rend.* 12th May 1902.

[3] The Lower Trias as here given has been compiled by Dr. W. Waagen and Dr. C. Diener; the Upper Trias by Dr. E. v. Mojsisovics, *Sitzb. Acad. Wien*, civ. (1895), p. 1279. See also Dr. Mojsisovics' Memoir in *Palæontologia Indica* (already cited), p. 155.

SKETCH OF THE CLASSIFICATION OF THE PELAGIC TRIAS, BY MESSRS. MOJSISOVICS, WAAGEN, AND DIENER.

	Series.	Stages.	Groups.	Mediterranean Triassic Province. Zones of the Pelagic Facies.	Mediterranean Triassic Province. Local Development of Strata.	Indian Triassic Province. Zones of the Pelagic Facies.	Indian Triassic Province. Local Development of Strata.
UPPER.	Bajuvarian	Rhaetic.		22. *Avicula contorta* zone.	Kössen Beds.		↑ Hochgebirgskalk of Himalaya.
		Juvavian.	Upper (Sevatian).	21. *Sirenites Argonautae* zone.			"Sagenites Beds"?
				20. *Pinacoceras Metternichi* ,,			
			Middle (Alaunian).	19. *Cyrtopleurites bicrenatus* ,,	Juvavian Halstatt Limestone.	Beds with *Spiriferina Griesbachi*.	
			Lower (Lacian).	18. *Cladiscites ruber* ,,		Zone of *Steinmannites undulato-striatus*.	
				17. *Sagenites Giebeli* ,,	Dachstein Limestone.	Zone of *Clydonautilus Griesbachi*.	
	Tirolian.	Carinthian.	Upper (Tuvalian).	16. *Tropites subbullatus* ,,	Sandling Beds.		
			Middle (Julian).	15. *Trachyceras aonoides* ,,	Raibl Beds.		*Tropites* limestone of Kalapani.
			Lower (Cordevolian).	14. *Trachyceras aon* ,,	Cassian Beds.		*b*. Daonella beds.
		Noric (Ladinian).	Upper (Longobardian).	13. *Protrachyceras Archelaus* ,,	Wengen Beds.		*a*. Beds with *Trachyceras tibeticum*.
			Lower (Fassanian).	12. *Dinarites avisianus* ,,	Marmolata Limestone.		
				11. *Protrachyceras Curionii* ,,	Buchenstein Beds.		
LOWER.	Dinarian.	Anisian.	Bosnian.	10. *Ceratites trinodosus* ,,	Upper Muschelkalk.	*Ptychites rugifer* zone.	Muschelkalk of the Himalaya.
			Balatonian.	9. *Ceratites binodosus* ,,	Lower Muschelkalk.	*Sibirites Prahlada* ,,	Brachiopod-beds with *Rhynchonella Griesbachi* (Himalaya).
		Hydaspian.				8. *Stephanites superbus* ,,	Upper Ceratite Limestone of Salt Range.
	Scythian.	Jakutian.		*Tirolites cassianus* zone.	Werfen Group of the Eastern Alps.	7. *Flemingites flemingianus* ,,	Ceratite Sandstone of the Salt Range. / *Subrobustus* beds of the Himalaya.
						6. *Flemingites radiatus* ,,	
						5. *Ceratites normalis* ,,	
						4. *Proptychites trilobatus* ,,	
		Brahmanian.	Gaudarian.			3. *Proptychites Lawrencianus* ,,	Ceratite Marls of the Salt Range.
						2. *Gyronites frequens* ,,	Lower Ceratite Limestone of Salt Range
			Gangetian.			1. *Otoceras Woodwardi* ,,	Otoceras Beds of the Himalaya.

Asia.—The Trias has a wide extension in this continent. From the Mediterranean basin it stretches through Asia Minor, where at Balia Maaden in Mysia dark shales and limestones enclose species of *Arcestes*, *Nautilus*, and *Halobia* (Juvavian and probably Sevatian), while at Ismid on the sea of Marmora Lower Triassic (Dinarian) forms have been obtained by Dr. F. Toula. Traces of still older parts of the system (Scythian) have been detected in the Araxes Pass near Djoulfa in Armenia. The Eastern Pamir has yielded three species of *Halorella* and *Monotis salinaria*, indicating the middle or upper section of the Juvavian stage. But it is within the confines of India that the most complete representation of the pelagic Trias has been met with in this continent. The Salt Range of the Punjab supplies a remarkably full display of the lowest or Scythian series of the system, as may be seen from the foregoing table, no fewer than seven distinct palæontological zones being said to be there traceable. Again, in the Himalayan region the Upper Triassic groups are well developed and contain a rich cephalopodan fauna. The Carinthian stage at Rimkin Paiar, Niti Pass, and Ralphu Glacier has yielded numerous genera and species of cephalopods indicative of the Julian group (*Anatomites*, *Arpadites*, *Cladiscites*, *Clydonautilus*, *Eutomoceras*, *Griesbachites*, *Hungarites*, *Isculites*, *Jovites*, *Joannites*, *Juvavites*, *Megaphyllites*, *Mojsvarites*, *Nautilus*, *Orthoceras*, *Paracladiscites*, *Placites*, *Pleuronautilus*, *Proarcites*, *Protrachyceras*, *Ptychites*, *Sagenites*, *Styrites*, *Tibetites*, *Trachyceras*). The Juvavian stage as displayed in the *Halorites*-limestone affords the richest assemblage of Upper Triassic cephalopods, of which 60 species have been obtained. They include the following additional genera: *Arcestes*, *Atractites*, *Anatibetites*, *Bambanagites*, *Clionites* (6 species), *Dionites*, *Dittmarites*, *Guembelites*, *Halorites* (5 sp.), *Helictites*, *Parajuvavites* (13 sp.), *Paratibetites* (5 sp.), *Pinacoceras*, *Sandlingites*, *Sirenites*, and *Steinmannites* (5 sp.). Above the *Halorites*-limestone come limestones and dolomites (100 to 120 metres) with *Spiriferina Griesbachi*, but the upward succession of cephalopods has not been traced further, though a fragment of a *Sagenites* has been obtained from the "Sagenites beds" of Dr. Diener.[1]

In the terrestrial Gondwana system of peninsular India, the Triassic series is believed to be represented by the Panchet group already mentioned (p. 1079), which consists chiefly of thick beds of pale coarse felspathic sandstones with bands of red clay and in the upper part occasional conglomerates, the whole in the Damodar valley not exceeding 1800 feet in thickness. These strata have supplied a number of land-plants (*Schizoneura*, *Vertebraria*, *Pecopteris*, *Thinnfeldia*, *Oleandridium*, *Glossopteris*, *Samaropsis*), but their most important palæontological characteristic lies in their being the chief repository of the animal remains of the Gondwana system. They have yielded *Estheria*, a number of labyrinthodonts (*Gonioglyptus*, *Glyptognathus*, *Pachygonia*), dicynodonts (*D. orientalis*, *Ptychosiagum*), and a deinosaur (*Epicampodon*).[2]

In north-western Afghanistan the Permo-Carboniferous group alluded to on p. 1079 passes upward into sandstones, limestones, and shales, which are regarded as probably Upper Triassic. At their base the typical shells *Halobia Lommeli* and *Monotis salinaria* are found, indicating a marine horizon, but the great mass of sediments are characterised by a terrestrial flora and intercalated seams of coal, as in the Gondwana system.[3]

Far to the east, in the island of Roth, at the eastern end of the Indian Archipelago, Triassic strata have been found containing the characteristic shell *Monotis salinaria*, with *Halobia* (*Daonella*). Traces of the pelagic type of the system have been detected at wide intervals along the western border of the Pacific. In five separate districts of Japan representatives of what may be the Anisian, Noric, and Juvavian stages have been noted (*Ceratites*, *Arpadites*, *Danubites*, *Japonites*, *Anolcites*, *Gymnites*, *Pseudomonotis ochotica*). The uppermost members of the Japanese Trias, paralleled with the Rhætic series of Europe, consist of a thick series of shales and sandstones with seams of anthracite and a characteristic flora of ferns and cycads, which include *Dictyophyllum*

[1] Mojsisovics, *Palæont. Indica, supra cit.* p. 127. [2] 'Manual of Geology of India,' p. 170.
[3] Griesbach, *Records Geol. Surv. India*, xix. (1886), p. 239.

acutilobum and *Baiera paucipartela*, also found in Europe.[1] The Scythian and Dinarian stages are developed in the coast province of Eastern Siberia near Vladivostock, where Brahmanian and Anisian cephalopods have been discovered. The *Pseudomonotis ochotica* has been found in the Gulf of Okhotsk.

Arctic Ocean.—The pelagic type of the Trias extends from the Pacific into the Arctic Ocean. It has been recognised among the New Siberian Islands off the mouth of the River Olenek, and still farther west in Spitzbergen. The Scythian stage with *Ceratites subrobustus*, and the Dinarian with *Hungarites triformis*, have been found in the former district. The Dinarian stage, with a *Posidonomya*-limestone below and a *Daonella*-limestone above, occurs in Spitzbergen. It fills the geologist with astonishment to find in these northern regions a rich cephalopod fauna embracing *Ceratites* (30 species), *Dinarites* (8), *Meekoceras* (6), *Xenodiscus* (4), *Sibirites* (3), *Prosphingites*, *Popanoceras* (5 or 6), *Ptychites* (6), *Nautilus* (2), *Pleuronautilus*, *Hungarites*, *Atractites*; also species of *Pseudomonotis* (11), *Daonella*, *Oxytoma*, *Avicula*, *Pecten*, *Gervillia*, *Cardita*, *Lingula*, *Spiriferina*, and *Rhynchonella*, together with remains of fish and reptiles (*Acrodus spitzbergensis*, *Ichthyosaurus polaris*, *Mixosaurus Nordenskiöldii*).[2] An upper Triassic terrestrial flora is likewise preserved in the strata of Research Bay, Spitzbergen.

Australasia.—Returning now to the Pacific basin we may follow the Triassic development southward. In New Caledonia the detection of *Phylloceras*, *Stenarcestes*, *Pseudomonotis* and other fossils indicates the probable existence there of the Juvavian stage.[3] In New Zealand also the same stage is probably represented by the strata which have furnished specimens of *Pseudomonotis*, *Halobia*, *Clydonautilus* and *Nautilus*.[4] In this colony Sir James Hector has grouped under the name of Trias a great thickness of strata divisible into three series. (1) The Oreti series—a thick mass of green and grey tuff-like sandstones and breccias, with a remarkable conglomerate (50 to 400 feet thick) containing boulders of crystalline rocks sometimes 5 feet in diameter, found both in the North and South Islands; fossils, chiefly Permian and Triassic, but with a *Pentacrinus* like a Jurassic species. (2) Above these beds lies the Wairoa series, containing *Monotis salinaria*, *Halobia Lommeli*, &c., and also plants, as *Dammara?*, *Glossopteris*, *Zamites*, &c. (3) The Otapiri series, which, from the commingling of fossils nearly allied to Jurassic species with others which are Triassic and some even Permian, and from the presence of many forms identical with those of the Rhætic formations of the Alps, is assigned to the Upper Trias or Rhætic division.[5]

The indications furnished by the rocks of New Zealand as to the southern limits of the open sea of Triassic time are supplemented and made clearer by the evidence afforded by the rocks of Australia. Thus in New South Wales an unmistakably terrestrial condition of sedimentation is revealed by the Hawkesbury series—a succession of yellowish-white sandstones and shales provisionally placed in this system. This series, which lies upon the Permian or Permo-Carboniferous Coal-measures, sometimes with no apparent break and sometimes with a decided unconformability, has been subdivided into three groups.[6] At the base lie (1) the Narrabeen beds, made up of sandstones and shales which range from 350 to 1900 feet in thickness. Their most conspicuous features are a band of purplish-red shale at the top, and the occurrence of

[1] 'Outlines of the Geology of Japan,' published by the *Imp. Geol. Surv. Tokyo*. 1900, p. 48.

[2] A. E. Nordenskiöld, *Geol. Mag.* **1876**, p. 741; A. Bittner and A. Teller, *Mém. Acad. St. Pétersbourg*, vol. xxxiii.; Mojsisovics, *Verhandl. k. k. Geol. Reichsanst.* 1886, No. 7.

[3] Mojsisovics, *Compt. rend.* 18th Nov. 1895.

[4] Mojsisovics, *Verhandl. Geol. Reichsanst.* 1886.

[5] 'Handbook of New Zealand,' p. 33. F. W. Hutton, *Q. J. G. S.* (1885), p. 202.

[6] C. S. Wilkinson, 'Notes on Geology of New South Wales,' Sydney, 1882, p. 53. O. Feistmantel, *Mem. Geol. Surv. N.S. Wales*, *Palæontology*, No. 3 (1890); R. Etheridge jun. *op. cit.* No. 1 (1888); T. W. Edgeworth David, Anniversary Address, *Roy. Soc. N.S. Wales*, 1896, p. 50.

flakes and veins of metallic copper among the purplish, gritty, and shaly strata, which have been described by Professor Edgeworth David as tuff.[1] In the centre come (2) the Hawkesbury sandstones, which form the picturesque cliffs around the coast of Port Jackson, and have furnished the stone for the principal public buildings in Sydney. They vary from about 250 feet thick in the Western division of the Blue Mountains to more than 1000 feet further east. They have yielded *Thinnfeldia*, *Gleichenites*, *Phyllotheca*, *Equisetum*, &c. At Gosford, near the base of the group, in a thin seam of grey shale, a large collection of fossil fishes has been obtained. The animals seem to have lived in some land-locked lake or estuary, and to have been killed in large numbers by the sudden silting up of the water with coarse sand and gravel. They belong to at least six genera, four of which occur in the European Trias. Of these four, two (*Dictyopyge* and *Semionotus*) are typically Triassic, while the third (*Belonorhynchus*) commonly ranges to the Lias, and the fourth (*Pholidophorus*) is best developed in the Jurassic system. The fifth genus (*Pristisomus*) is new, but scarcely higher in rank than *Semionotus*, while the sixth (*Cleithrolepis*) has only been definitely recognised in the Stromberg beds of South Africa, the age of which may be Triassic or Lower Jurassic.[2] The group has likewise yielded *Mastodonsaurus* and a marine gasteropod (*Tremanotus*). The highest member (3), the Wianamatta shales, consists of dark grey strata with clay-ironstone and thin seams of coal. Among its fossils, which are abundant in the lower part, dwarfed forms of Unionidæ are conspicuous; *Mastodonsaurus* has likewise been found, together with *Palæoniscus* and *Cleithrolepis*. The tolerably abundant plants are chiefly ferns (*Thinnfeldia*, *Macrotæniopteris*).

Africa.—In South Africa the "Karoo beds," which have already been referred to as spreading over a wide area of country, in nearly horizontal sheets of incoherent sandy materials, and from which so remarkable an assemblage of amphibian and reptilian remains has been obtained, appear to represent the various formations which in other regions constitute the Permian and Triassic systems. Their lower parts may be of Carboniferous age, while their higher members may be Rhætic. We have considered the lower and middle groups of the three divisions into which they have been separated, and have seen the remarkable similarity of their palæontology to that of the Lower Gondwana formations of India. The third or upper group, known as the Stormberg beds, presents a not less striking resemblance in its flora to that of the Hawkesbury series of New South Wales. Among the species common to Africa and Australia are *Sphenopteris elongata*, *Thinnfeldia odontopteroides*, *T. trilobata*, *Tæniopteris Carruthersi*, *T. Daintreei* and *Podozamites elongatus*. The Stromberg beds have likewise furnished *Baiera Schencki*, and species of *Pecopteris*, *Alethopteris*, &c. This assemblage of plants does not include *Glossopteris*, and indicates a later flora probably of Triassic age. The group may be paralleled with the Panchet rocks of India. It has also yielded *Dicynodon* and other reptilian remains.

North America.—Rocks which are regarded as equivalent to the European Trias cover a large area in North America. On the Atlantic coast, they are found in Prince Edward's Island, New Brunswick, and Nova Scotia; in Connecticut, New York, Pennsylvania, and North Carolina; in Honduras and along the chain of the Andes into Brazil and the Argentine Republic. On the western side of the Rocky Mountains they reappear in Idaho and stretch through California into British Columbia. They consist mainly of red sandstones, passing sometimes into conglomerates, and often including shales and impure limestones. But an important distinction may be drawn between their development in the eastern and central parts of the continent, on the one hand, and along the Pacific slope on the other. In the latter region it is the pelagic type of the system which is developed, in the former it is the lagoon type.

On the Pacific slope and eastwards into Idaho, strata which may represent the Trias

[1] *Rep. Austral. Assoc.* Sydney, i. (1887), p. 275.

[2] A. S. Woodward, *Mem. Geol. Surv. N.S Wales, Palæontology*, No. 4 (1890), p. 54.

are estimated to reach a thickness of sometimes as much as 14,000 or 15,000 feet. The stages of the system as worked out in the Mediterranean basin have been more or less clearly identified among these strata by means of their fossils. What may be the Jakutian stage is found in south-eastern Idaho among the so-called *Meekoceras*-beds of Aspen Mountain, which contain *Meekoceras gracilitatis*, *M. aplanatum*, *M. mushbachianum*, and a species of *Arcestes*. The same stage appears to occur in the Santa Ana Mountains, California, where a species of *Pseudomonotis* like *P. clarai* of the Werfen group, a trachyostracan ammonite and what is probably a *Rhynchonella* have been found. In Shasta County, of the same State, a series of shales with *Trachyceras ?*, *Proarcestes*, and *Pseudomonotis* may be Dinarian. Fossils belonging to the Muschelkalk horizon have been obtained from the Star Peak Range in Nevada—*Trachyceras*, *Acrochordiceras*, *Eutomoceras*, *Arcestes*, *Orthoceras*, genera common to the Trias of the Mediterranean province. The Noric and Carinthian stages of Plumas and Shasta Counties, California, are well represented by a large list of fossils, among which twenty or more species are believed to be identical with or closely related to forms found in the Eastern Alps, such as species of *Eutomoceras*, *Juvavites*, *Sagenites*, *Tropites* (including *T. subbullatus* and *torquillatus*), *Trachyceras*, *Tirolites*, *Nannites*, *Halobia* (*H. Lommeli*, *superba*), and *Monotis salinaria*. The uppermost member of the Trias of California, the Hosselkus limestone, abounds in cephalopods. Its upper part, containing *Rhabdoceras*, *Tropites*, *Paratropites* and *Halorites*, may possibly belong to the Juvavian stage.[1] The Noric stage has also been found in British Columbia.

In the interior of the Continent, deposits marking inland seas cover vast areas from Wyoming to New Mexico. They contain beds of gypsum and rock-salt, and have yielded a few lacustrine or brackish water shells. They occupy the position of the Trias, and are from 600 to 2000 feet thick. It is on the Atlantic border, however, that the lagoon type of the Trias is best developed. The strata which represent the Triassic water-basins may be traced in separate areas from Nova Scotia to South Carolina. They have long been known and described in Connecticut, and in the wider tract from New Jersey through Pennsylvania and Maryland into Virginia. The term "Newark series" has been applied to this group of strata, consisting chiefly of red sandstones, interstratified with conglomerates, breccias, shales, occasional impure limestones and, in Connecticut, several intercalated sheets of igneous rocks. In the last-named state they have been estimated to be from 7000 to 10,000 feet thick.[2]

The flora obtained from these strata presents a general resemblance to that of the European Trias. In Connecticut and New Jersey it includes horse-tails (*Equisetum*, *Schizoneura*), cycads (*Pterophyllum*, some European species), *Zamites*, *Otozamites*, *Sphenozamites*, *Nilssonia polymorpha*, *Dioonites*), ferns (*Pecopteris*, *Neuropteris*, *Taeniopteris*, *Clathropteris*) and conifers (*Cheirolepis*).[3] In Virginia, where two distinct

[1] F. B. Meek, *U.S. Geol. Explor. Fortieth Parallel*, vol. iv. Part i.; A. Hyatt, *Bull. Geol. Soc. Amer.* iii. (1892); Gabb, *Palæontology of California*, vol. i.; J. F. Whiteaves, *Contributions to Canadian Palæontology*, i. Part ii. p. 127; J. P. Smith, *Journ. Geol.* vol. ii. p. 602; iii. p. 374; iv. p. 385.

[2] Professor Emerson, *Mon. U.S. G. S.* xxix. (1898), pp. 351-517. W. M. Davis, *7th Ann. Rep. U.S. G. S.* (1888), p. 455; 18th *Ann. Rep. U.S. G. S.* Part ii. (1898), pp. 1-192. I. C. Russell, *B. U.S. G. S.* No. 85, (1892). W. H. Hobbs, *21st Ann. Rep. U.S. G. S.* 1901, Part iii. pp. 7-162. Numerous other non-official papers have been published on the "Newark system." The distribution of the rocks and the theories regarding their origin have been stated by Mr. Russell in the paper here cited, which also gives an exhaustive bibliography of the subject. The most recent discussion will be found in Mr. Hobbs' essay, which contains also a chapter on the tilting and dislocation of the Pomeraug Valley, and another on the results of the denudation of the region.

[3] J. S. Newberry, *Monograph U.S. Geol. Survey*, vol. xiv. (1888), and *Amer. Journ. Sci.* xxxvi. (1888), p. 342.

Mesozoic floras have been preserved, the older appears to be not more ancient than the Rhætic stage. So abundant is the vegetable matter in the sandy strata of the series as to form seams of workable coal, one of which is sometimes 26 feet thick. The plants include species of *Equisetum*, *Schizoneura*, *Macrotæniopteris*, *Acrostichites*, *Cladophlebis*, *Lonchopteris*, *Clathropteris*, *Pterophyllum*, *Ctenophyllum*, *Podozamites*, *Cycadites*, *Zamiostrobus*, *Baiera*, *Cheirolepis*, &c. Again in North Carolina a coal-bearing formation occurs with a similar flora, 41 per cent of the plants being also found in Virginia.[1]

The fauna of the North American Triassic rocks is remarkable chiefly for the number and variety of its vertebrates. The labyrinthodonts are represented by footprints, from which upwards of fifty species have been described. Saurian footprints have likewise been recognised ; in a few cases their bones also have been found. Some of the vertebrates had bird-like characteristics, among others that of three-toed hind feet, which produced impressions exactly like those of birds (pp. 1089, 1090). But, as already remarked, it is by no means certain that what have been described as "ornithichnites" were not really made by deinosaurs. The small insectivorous marsupial (*Dromatherium*) above referred to, found in the Trias of North Carolina, is the oldest American mammal yet known.

Section ii. Jurassic.

This great series of fossiliferous rocks, first recognised by William Smith in the geological series in England, received originally the name of "Oolitic" from the frequent and characteristic oolitic structures of many of its limestones. Lithological names being, however, objectionable, the term "Jurassic," applied by the geologists of France and Switzerland to the great development of the rocks among the Jura Mountains, has now been universally adopted to embrace the whole series of formations from the top of the Rhætic strata up to the base of the Cretaceous system.

§ 1. General Characters.

Jurassic rocks have been recognised over a large part of the world. But they do not present that general uniformity of lithological character so marked among the Palæozoic systems, especially the older members of the series. The lithology indeed can be seen to become more diversified as we ascend in the geological record. The suite of formations now to be described changes as it passes from England across France, and is replaced by a distinctly different type in Northern Germany, and by another in the Alps. If we trace the system farther into the Old World we find it presenting still another aspect in north-western India, while in America the meagre representatives of the European development have again a facies of their own. Hence no generally applicable petrographical characters can be assigned to this part of the geological record.

The flora of the Jurassic period, so far as known to us, was

[1] W. M. Fontaine, *Monogr. U.S. Geol. Surv.* vol. vi. (1883). The younger Mesozoic flora of Virginia is probably Neocomian (*postea*, p. 1210). See also Mr. Lester Ward's important memoir on the "Status of the Mesozoic Floras of the United States," Part i., in *20th Ann. Rep. U.S. G. S.* 1900.

essentially gymnospermous.[1] The Palæozoic forms of vegetation traceable up to the close of the Permian system are here absent. Equisetums,

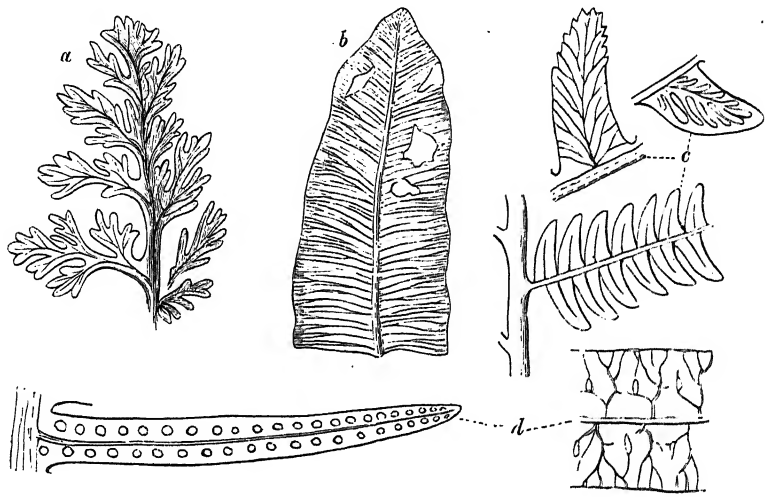

Fig. 417.—Jurassic Ferns (Lower Oolite).
a, Sphenopteris; *b*, Tæniopteris major, Lindl. and Hutt. (⅔); *c*, Todites Williamsoni, Brongn. (nat. size and mag.); *d*, Laccopteris polypodioides, Brongn. (nat. size and mag.).

so common in the Trias, are still abundant, one of them (*E. arenaceum*) attaining gigantic proportions. Ferns likewise continue plentiful, some of the chief genera being *Cladophlebis*, *Coniopteris*, *Dictyophyllum*, *Laccopteris*, *Sagenopteris*, *Sphenopteris*, *Todites*, and *Tæniopteris* (Figs. 417, 418). The cycads (Fig. 419), however, are the dominant forms, in species of *Ctenis*, *Dioonites*, *Nilssonia*, *Otozamites*, *Podozamites*, *Ptilozamites* *Williamsonia*, &c. The family of Ginkgoaceæ, represented by the living Ginkgo or Maiden-hair tree of China and Japan, appeared in the Jurassic forests in species of *Ginkgo*, *Baiera*, and *Beania*. From the upper part of the system in Portugal some plants have been obtained, which, if really primitive angiosperms, as has been supposed, are the earliest known forerunners of the

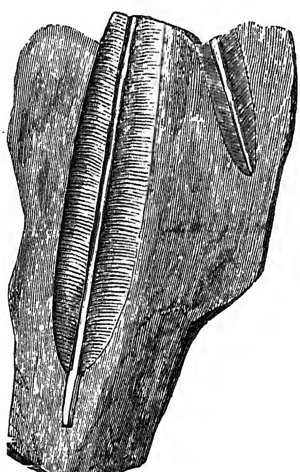

Fig. 418.—Jurassic Fern—Tæniopteris vittata, Brongn. (½).

[1] The entire known Jurassic flora of Britain up to the top of the Portlandian stage was estimated in 1882 to comprise between 60 and 70 genera and about 200 species—a scanty fragment of the whole vegetation of the period. Etheridge, *Q. J. G. S.* 1882, Presidential Address.

familiar plants of the present time.[1] Conifers are found in some numbers, particularly the genera *Araucarites*, *Brachyphyllum*, *Cryptomerites*, *Nageopsis*, *Pagiophyllum*, *Pinus*, *Taxites*, and this flora appears to have flourished luxuriantly even as far north as Spitzbergen, where the large number of cycads gives an almost tropical aspect to the Jurassic vegetation of this Arctic island.[2]

The Jurassic fauna[3] presents a far more varied aspect than that of any of the preceding systems. Owing to the intercalation of fresh-water, and sometimes even terrestrial, deposits among the marine formations, traces of the life of the lakes and rivers, as well as of the land itself, have been to some extent entombed, besides the preponderant marine forms. The conditions of sedimentation have likewise been

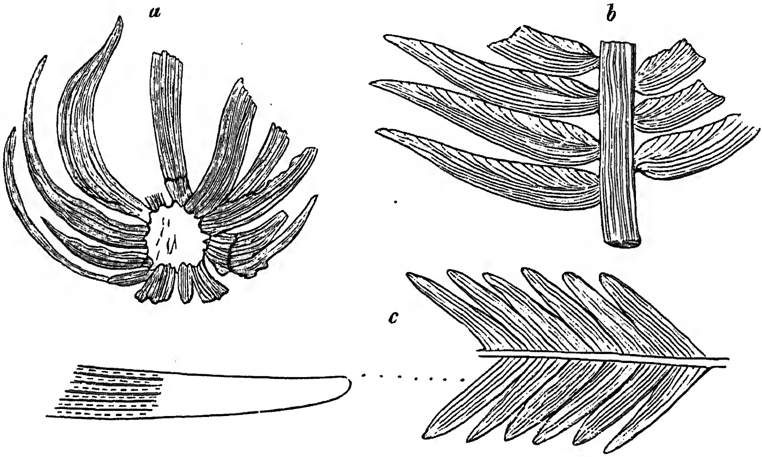

Fig. 419.—Jurassic Cycads (Lower Oolites).
a, Williamsonia gigas, Carr (½); *b*, Otozamites acuminatus, Lindl. and Hutt. (½); *c*, Williamsonia pecten, Phill. (nat. size and mag.).

favourable for the preservation of a succession of varied phases of marine life. Professor Phillips directed attention to the remarkable ternary arrangement of the English Jurassic series.[4] Argillaceous sediments are there succeeded by arenaceous, and these by calcareous, after which the

[1] De Saporta, *Compt. rend.* cxi. p. 812. L. F. Ward, 16*th Ann. Rep. U.S. G. S.* p. 520.

[2] O. Heer, *K. Svensk. Vet. Akad. Handl.* xiv. No. 5, p. 1. The Jurassic flora is discussed by L. F. Ward in the memoir cited on p. 1111. See also his description of a new genus (*Cycadella*) and 20 new species of Cycadean trunks from the Jurassic rocks of Wyoming, *Proc. Washington, Acad. Sci.* i. (1900), pp. 253-300. A. C. Seward, "The Jurassic Flora," forming part of the Catalogue of Mesozoic Plants published by the Trustees of the British Museum, Part i. 1900. Fontaine, *Monogr. VI. U.S. G. S.* 1883.

[3] The total Jurassic fauna of Britain up to the top of the Portlandian stage was estimated in 1882 to include 450 genera and 4297 species, which is likewise but a small proportion of the whole original fauna; Etheridge, *op. supra cit.*

[4] 'Geology of Oxfordshire,' &c. p. 393.

argillaceous once more recur. These changes are more or less local in their occurrence, but five repetitions of the succession are to be traced from the top of the Lias to the top of the Portlandian stage. Such an alternation of sediments points to interrupted depression of the sea-bottom.[1] It permitted the growth and preservation of different kinds of marine organisms in succession over the same areas,—at one time sand-banks, followed by a growth of corals, with abundant sea-urchins and shells, and then by an inroad of fine mud, which destroyed the corals, but in which, as it sank to the bottom, the abundant cephalopods and other mollusks of the time were admirably preserved.

Sponges abounded on some parts of the floor of the Jurassic seas. Lithistid genera form thick beds in the Upper Jurassic Spongitenkalk of Franconia and other parts of the European continent. Calcareous sponges are represented by numerous genera (*Peronidella*, *Corynella*, *&c.*). Professor Rothpletz has described horny sponges from the Upper Lias of

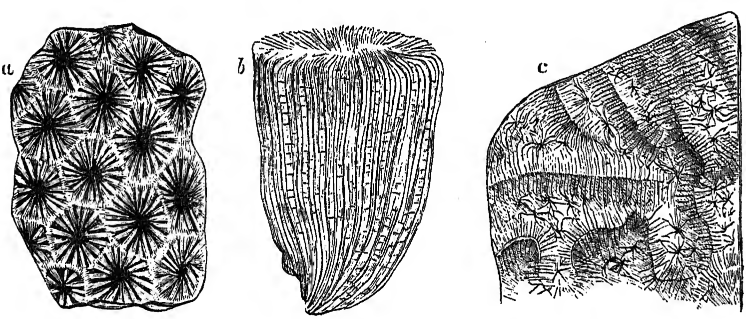

Fig. 420.— Jurassic Corals (Middle Oolite).
a, Isastræa helianthoides, Goldf.; *b*, Montlivaltia dispar, Phill.; *c*, Comoseris irradians, M. Edw.

Würtemberg, and more recently an example from the Dogger of the Bernese Oberland in which recognisable diatoms were enclosed.[2]

A characteristic feature of the Jurassic fauna is the abundance of its beds or banks of coral. During the time of the Corallian formation, in particular, the greater part of Europe appears to have been submerged beneath a coral sea. Stretching through England from Dorsetshire to Yorkshire, these coral accumulations have been traced across the Continent from Normandy to the Mediterranean, over the east of France, through the whole length of the Jura Mountains, and along the flank of the Swabian Alps. The corals belonged to the genera *Isastræa*, *Astrocœnia*, *Thamnastræa*, *Anabacia*, *Thecosmilia*, *Montlivaltia*, &c. (Fig. 420). In the Jurassic seas generally Echinoderms were abundant, but the types of Palæozoic time had now entirely disappeared. The Crinoids were now represented by comparatively few forms, such as the genera *Pentacrinus* (Fig. 421), *Millericrinus*, and *Apiocrinus*. Among these the multiplication of identical or nearly identical parts reaches a climax in

[1] *Ante*, p. 649.

[2] *Z. D. G. G.* xlviii. (1896), p. 905; 1900, pp. 154, 388.

the *Pentacrinus fossilis*, which is estimated to have possessed no fewer than 600,000 distinct ossicles. There were likewise several forms of star-fishes, but it is in the great profusion of echinoids that the echinoderms now

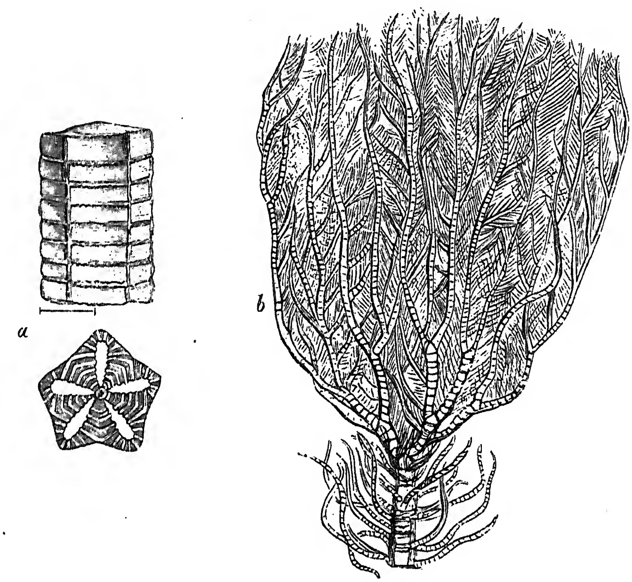

Fig. 421.—Lias Crinoids.
a, Isocrinus basaltiformis, Goldf. (side view and end view of part of stem); *b*, Pentacrinus fossilis, Blum. (=briareus, Mill.) (½).

begin to be distinguished. Among these the genera *Acrosalenia*, *Cidaris* (Fig. 422), *Hemicidaris*, *Glypticus*, *Pseudodiadema*, *Hemipedina*, *Nucleolites* (*Echinobrissus*), *Clypeus*, *Pygaster*, *Pygurus*, and *Collyrites* were conspicuous. Polyzoa of creeping, foliaceous, and dendroid types abound on many horizons in the Jurassic system. They include the genera *Stomatopora*, *Proboscina*, *Berenicea*, *Diastopora*, *Idmonea*, *Spiropora*, *Apsendesia*, *Ceriopora*, *Heteropora*. They occur plentifully in the Pea-grit beds of the Inferior Oolite near Cheltenham, and Forest Marble near Bath, and still more abundantly near Metz and near Caen.[1] The brachiopods (Figs. 423, 424) continue to decrease in importance compared to the prominence they enjoyed in Palæozoic time. So far as known, they chiefly belong to the Terebratulidæ, Rhynchonellidæ, and Thecidiidæ, though the Lingulidæ, Discinidæ, and Craniidæ still occur as they do in our present seas The last of the ancient group of the Spirifers were represented

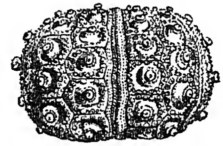

Fig. 422.—Jurassic Sea-Urchin. Cidaris florigemma, Phill. (½) Corallian.

[1] F. D. Longe, *Geol. Mag.* 1881, p. 23. British Museum "Catalogue of Jurassic Bryozoa," by J. W. Gregory, 1896.

by *Spiriferina* and *Suessia*, which did not outlive the Jurassic period. The Athyrids also now die out with the genera *Amphiclina* and *Koninckella*. Among the lamellibranchs (Figs. 425-428) a number of still living families now began their existence, such as the Arcidæ, Anomiidæ, Anatinidæ, Thraciidæ, Cyrenidæ, Isocardiidæ, Veneridæ, Tellinidæ, Pholadidæ, and Donacidæ. Some of the more abundant Jurassic genera are *Avicula*, *Pseudomonotis*, *Aucella*, *Posidonomya*, *Gervillia*,

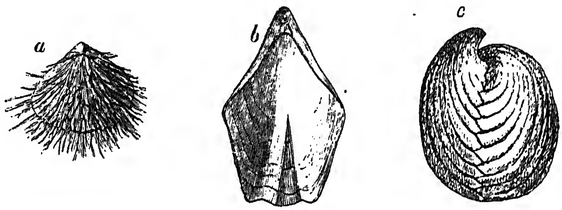

Fig. 423.—Oolitic Brachiopods.
a, Rhynchonella (Acanthothyris) spinosa, Schloth. (½), Lower Oolite; *b*, Terebratula Phillipsii, Mor. (½), Lower Oolite; *c*, Rhynchonella pinguis, Rœm., Middle Oolite.

Ostrea, *Gryphæa*, *Exogyra*, *Lima*, *Pecten*, *Pinna*, *Astarte*, *Cardinia*, *Cardium*, *Gresslya*, *Hippopodium*, *Modiola*, *Pleuromya*, *Cyprina*, *Isocardia*, *Pholadomya*, *Goniomya*, and *Trigonia*. Some of these genera, particularly the tribe of oysters, are specially characteristic: *Gryphæa*, for example, occurring in such numbers in some of the Lias limestones as to suggest for these strata the name of "Gryphite Limestone," and again in the so-called "Gryphite Grit" of the Inferior Oolite. Different species of *Trigonia*,[1]

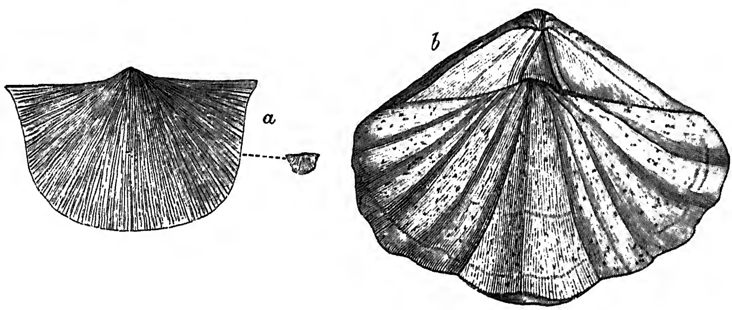

Fig. 424.—Lias Brachiopods.
a, Cadomella Moorei, Dav. (nat. size and enlarged); *b*, Spiriferina Walcottii, Sby.

a genus now restricted to the Australian seas, are likewise distinctive of horizons in the middle and upper part of the system. Of the gasteropoda some families that can be traced far back into Palæozoic time and still survive at the present day reached their highest development

[1] This genus affords an instructive example of the remarkable changes of form which some genera of shells have undergone. See Lycett's monograph on Trigonia, *Palæontograph. Soc.*

in Jurassic seas. Such were the Pleurotomariidæ, Turbinidæ, Neritopsidæ and Pyramidellidæ. The last of the pteropod-like genus *Conularia*, which attained its culmination in the Silurian period, now finally died out in the time of the Lias. The more abundant gasteropod genera

a

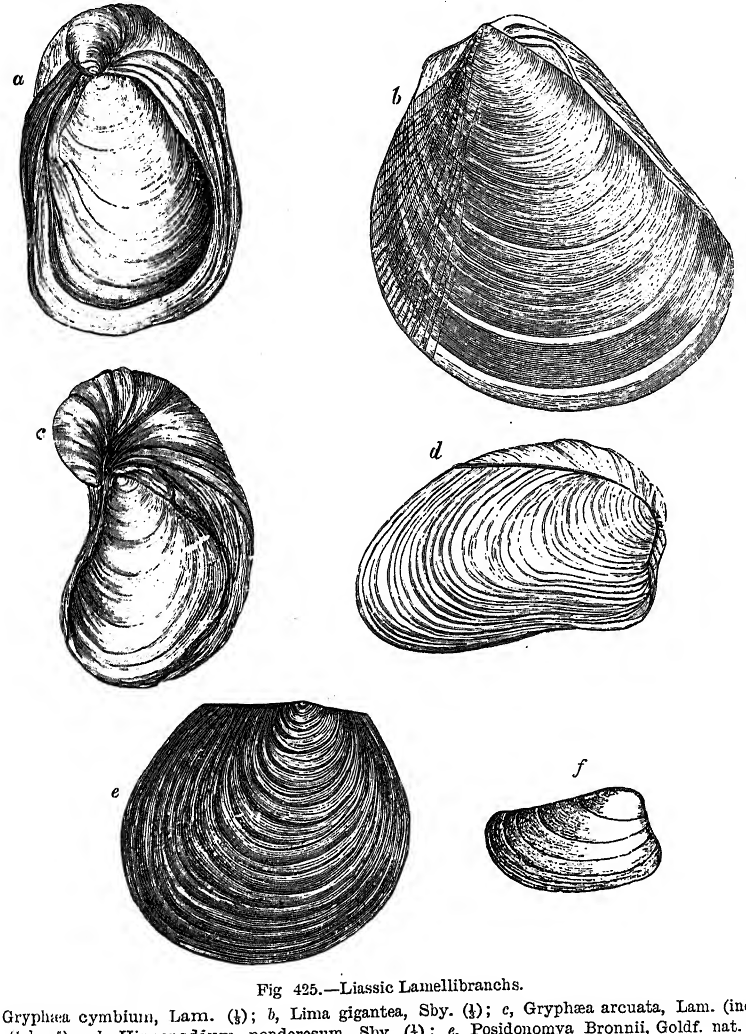

Fig 425.—Liassic Lamellibranchs.

a, Gryphæa cymbium, Lam. (⅓); *b*, Lima gigantea, Sby. (⅓); *c*, Gryphæa arcuata, Lam. (incurva, Syb. ⅘); *d*, Hippopodium ponderosum, Sby. (¼); *e*, Posidonomya Bronnii, Goldf. nat. size); *f*, Nucula Hammeri, Defr.

(Fig. 429) in the Jurassic system of Britain are *Actæonina*, *Alaria*, *Amberleya*, *Cerithium*, *Natica*, *Nerinæa*, *Pleurotomaria* (nearly eighty species), *Pseudomelania*, *Purpuroidea*, *Trochus*, *Turbo*, and *Turritella*.[1]

[1] W. H. Hudleston and E. Wilson, "Catalogue of British Jurassic Gasteropoda," 1892.

But the most important element in the molluscan fauna was undoubtedly supplied by the cephalopods. The Ammonites, which reached, their climax in Triassic time, though still abundant in Jurassic waters were already on the wane. Of the nine families which have been observed in the Trias only one (that of the Phylloceratidæ) can be traced through the Jurassic and Cretaceous formations. Of the dibranchiate

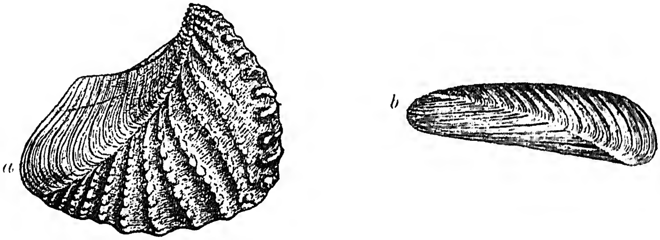

Fig. 426.—Lower Oolitic Lamellibranchs.
a, Trigonia navis, Lam. (½); *b*, Modiola sowerbyana, D'Orb. (½).

types the Belemnoidea, which begin in the Trias, rapidly reach a remarkable abundance and variety in the Jurassic formations. But they decline in the Cretaceous system, and are represented at the present day by only a single living genus (*Spirula*). The Sepioidea make their first appearance in the Lias (*Beloteuthis*, *Geoteuthis*, *Teuthopsis*), and still survive in our modern cuttle-fishes. As has been apparent in the foregoing

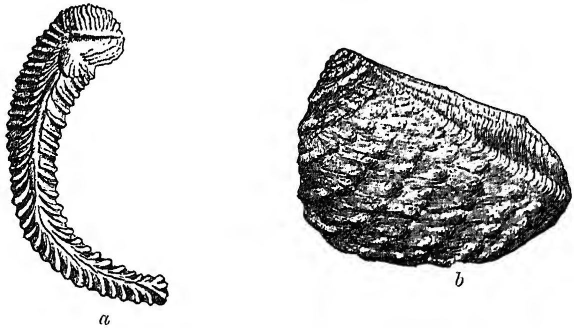

Fig. 427.—Middle Oolitic Lamellibranchs.
a, Ostrea (Alectryonia) hastellata, Schloth. (½); *b*, Trigonia clavellata, Sby. (½).

description of the Trias, and as will be still more noticeable in the following account of the Jurassic system, the cephalopoda possess a great importance to the geologist, for their limited vertical range makes them extremely valuable in marking successive life-zones.[1] The Jurassic formations have been divided into a series of platforms, each characterised by

[1] Students interested in the phylogeny of these organisms will find a suggestive paper by A. Hyatt, "Evolution of the Faunas of the Lower Lias," in the *Proc. Boston Soc. Nat. Hist.* xxiv. (1888), p. 17.

some predominant species or group of Ammonites. In the older part of the Jurassic system the genera *Arietites*, *Ægoceras*, *Amaltheus*, *Harpoceras*, *Lytoceras*, *Oxynoticeras*, *Phylloceras*, and *Stepheoceras* are characteristic (Figs. 441, 442, 443). Higher up, besides some of these genera, we find

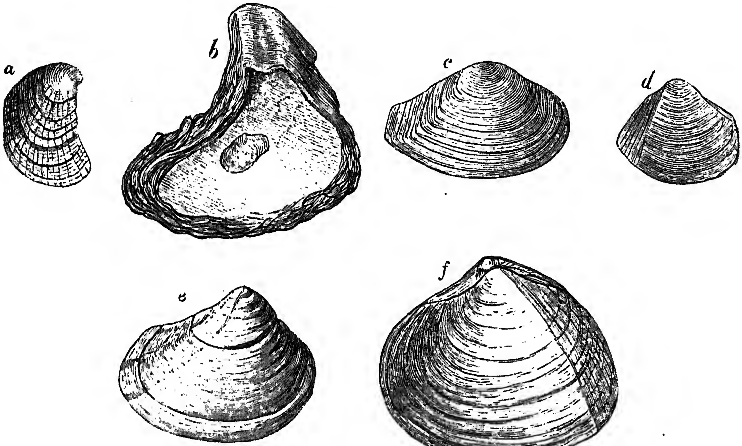

Fig. 428.—Upper Oolitic Lamellibranchs.

a, Exogyra virgula, D'Orb.; *b*, Ostrea deltoidea, Sby. (¼); *c*, Astarte hartwellensis, Sby. (⅓); *d*, Protocardia striatula, Sby. (½); *e*, Trigonia gibbosa, Sby. (½); *f*, Protocardia dissimilis, Sby. (½).

Cosmoceras, *Perisphinctes*, *Cardioceras*, *Kepplerites*, and *Aspidoceras* (Fig. 445), and in the upper parts *Perisphinctes*, *Olcostephanus*, *Reineckia*, and *Oppelia*. The Belemnites (Fig. 430), like the Ammonites, though in a less degree, serve to mark life-zones.

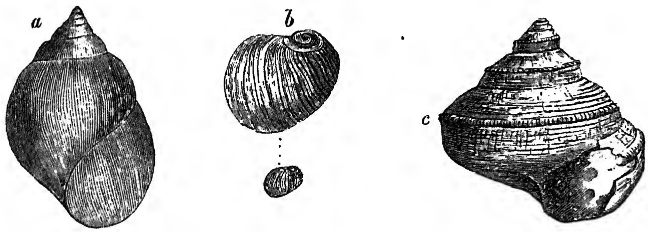

Fig. 429.—Jurassic Gasteropods.

a, Natica hulliana, Lyc. (Lower Oolite); *b*, Nerita costulata, Desh. (Lower Oolite, nat. size and mag.); *c*, Pleurotomaria reticulata, Sow. (Kimeridge clay, ½).

No contrast can be more marked than between the crustacean fauna of the Jurassic and that of the Palæozoic systems. The ancient trilobites and eurypterids are now replaced by tribes of long-tailed lobsters and prawns (*Penæus*, *Aeger*, *Eryon*, *Scapheus*, *Eryma*, *Magila*, &c.) while the earliest brachyurous forms[1] (*Prosopon*) now make their appearance.

[1] For an account of the Jurassic decapods of North Germany see G. Krause, *Z. D. G. G.* 1891, p. 171.

These were accompanied by a few Isopods, some of which have been excellently preserved in the finer-grained strata (*Archæoniscus, Cyclosphæroma*).

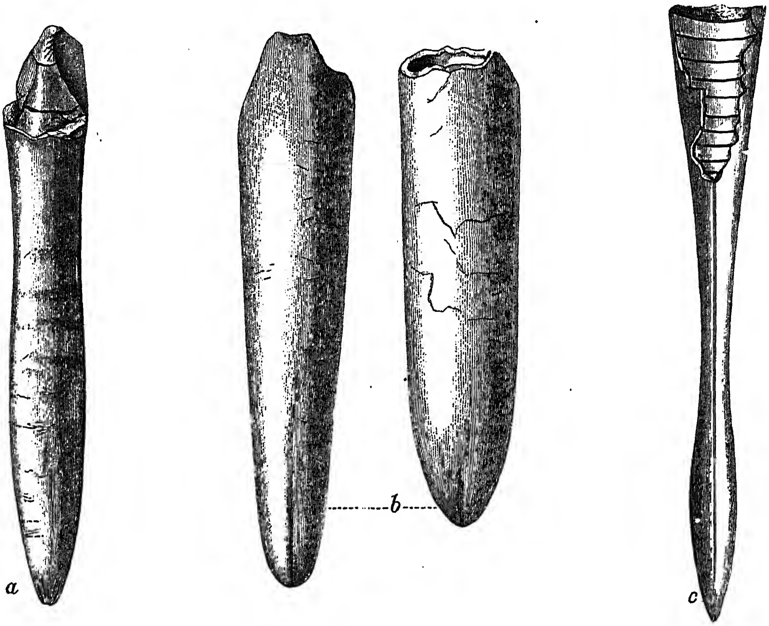

Fig. 430.—Jurassic Belemnites.
a, Belemnites paxillosus, Schloth. (Lias, ½); *b*, B. irregularis, Schloth. (Lias and Lower Oolite, nat. size); *c*. B. hastatus, Blainv. (Middle Oolite).

Here and there, particularly in the Jurassic series of England and Switzerland, thin bands occur containing the remains of terrestrial insects (Fig. 431). The neuropterous forms predominate, including

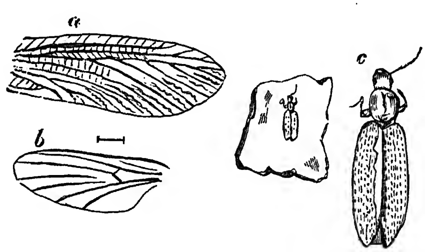

Fig. 431.—Insects, Purbeck Beds.
a, b, Wings of Neuropterous Insects (*Orthophlebia*) (nat. size and mag.); *c*, *Carabidium elongatum* (nat. size and mag. Brodie, 'Foss. Insects,' pl. ii. and v.)

remains of dragon-flies, mayflies, and white-ants. There are also orthopterous genera, such as cockroaches, grasshoppers, earwigs, crickets, and walking-stick insects. The elytra of beetles, owing to their durability,

have been found in some numbers in certain favourable deposits, such as

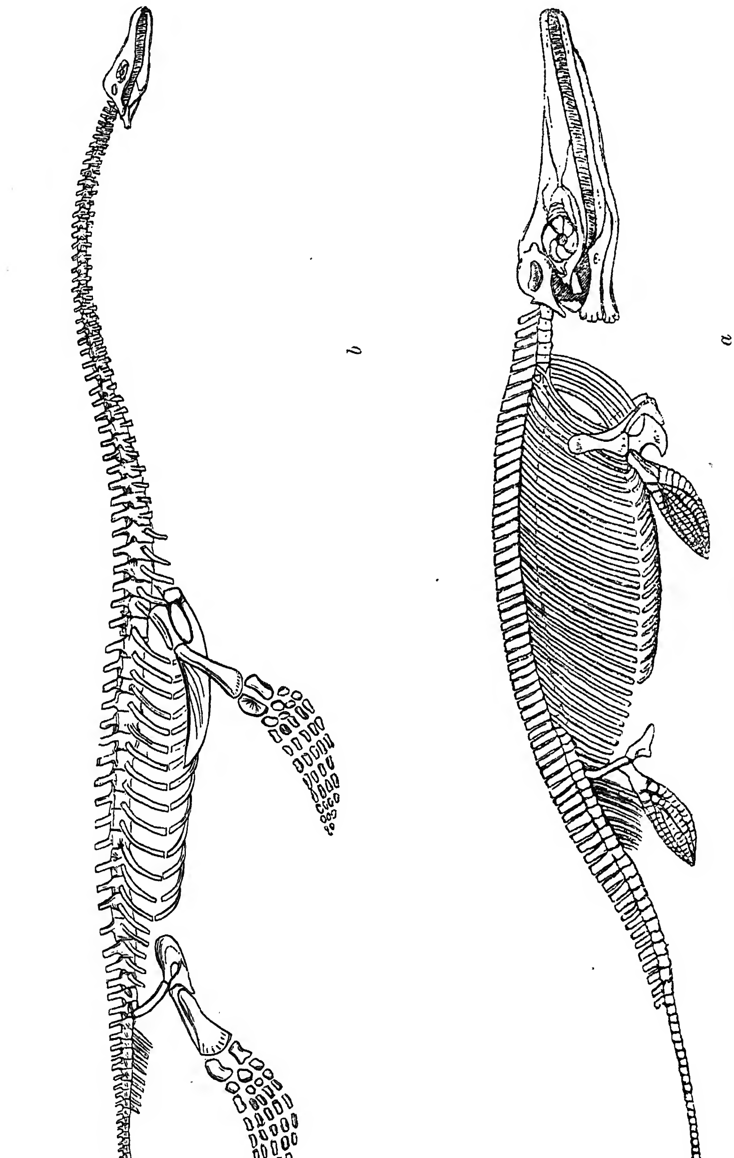

Fig. 432.—Jurassic Enaliosaurs or Sea-lizards.
a, Ichthyosaurus communis, Conyb. (restored by Conybeare and Cuvier); *b*, Plesiosaurus dolichodeirus, Conyb. (restored by Conybeare).

are met with in the Lias, Stonesfield Slate, and Purbeck beds of England.

They belong to still familiar types (Curculionidæ, Chrysomelidæ, Buprestidæ, Elateridæ, Melolonthidæ). The hemiptera are well represented even as low down as the Lias. The earliest flies (Diptera) are found in the same formation, and they occur in different platforms higher up in the system. The earliest ants (Hymenoptera) have likewise been furnished by the Lias and the fine-grained upper Jurassic limestones.[1]

In few departments of the animal kingdom was the advent of Mesozoic time more marked than among the fishes. The Palæozoic types, with their heterocercal tails, had nearly died out. The sharks and rays were well represented by species of *Acrodus* and *Hybodus*, while the ganoids appeared in numerous, mostly homocercal genera, such as *Lepidotus*, *Dapedius*, *Tetragonolepis*, *Mesodon*, *Microdon*, *Gyrodus*, *Eugnathus*, *Caturus*, *Euthynotus*, and *Pholidophorus*. A few teleosteans occur (*Leptolepis*, *Thrissops*).

But the most impressive feature in the life of the Jurassic period was the abundance and variety of the reptilian forms. Mesozoic time, as already remarked, has been termed the "Age of Reptiles," and it was especially during the Jurassic period that reptilian types reached their maximum development. The ancient order of labyrinthodonts and the abundant anomodonts of the Trias disappeared, and their places were taken by other new orders which, after a wonderful profusion of types had been reached, died out in Mesozoic time. The earliest known Chelonia, which come from the Keuper of Würtemburg (*Proganochelys*), are succeeded in the upper Jurassic formations by other forms which closely resemble living types. Numerous fragments, which may be lacertilian, have been obtained from the Purbeck Beds. The bones of various crocodilian genera occur, such as *Teleosaurus*, *Pelagosaurus*, *Steneosaurus*, *Mystriosaurus*, and *Goniopholis*. *Steneosaurus*, found in the Yorkshire Lias and the Stonesfield Slate, was a true carnivorous crocodile, measuring about 18 feet in length, which ventured perhaps more freely to sea than the gavial of the Ganges or the crocodile of the Nile. Of the long-extinct reptilian types, one of the most remarkable was that of the enaliosaurs or sea-lizards. One of these, the *Ichthyosaurus* (Fig. 432, *a*), was a creature with a fish-like body, two pairs of strong swimming paddles, a vertical tail-fin, and a head joined to the body without any distinct neck, but furnished with two large eyes, having a ring of bony plates round the eye-ball, and with teeth that had no distinct sockets. Some of the skeletons of this creature exceed 24 feet in length. Contemporaneous with it was the *Plesiosaurus* (Fig. 432, *b*), distinguished by its long neck, the larger size of its paddles, the smaller size of its head, and the insertion of its teeth in special sockets, as in the higher saurians. These creatures seem to have haunted the shallow Liassic seas, and, varying in species with the successive ages, to have survived till towards the close of Mesozoic time.[2] The genus

[1] A. G. Butler, *Geol. Mag.* x. (1873) p. 2; i. 2nd ser. (1874) p. 446. Scudder, *B. U.S. G. S.* No. 71 (1891), p. 175, and authorities there cited.

[2] On the distribution of the Plesiosaurs see a table by G. F. Whidborne, *Q. J. G. S.* (1881), p. 480.

Pliosaurus, related to the last-named, was distinguishable from it by the shortness of its neck and the proportionately large size of its head. Another extraordinary reptilian type was that of the pterodactyles or flying reptiles (Ornithosauria or Pterosauria), which were likewise peculiar to Mesozoic time. These huge, winged, bat-like creatures had large heads, teeth (when present) in distinct sockets, eyes with bony plates like the *Ichthyosaurus*, the fifth finger of each fore-foot prolonged to a great length, for the purpose of supporting a membrane for flight, and bones, like those of birds, hollow and air-filled[1] (Figs. 433-437). The best-known genus, *Pterodactylus*, had a short tail and jaws furnished from end to end with long teeth. Others were *Dimorphodon*, distinguished

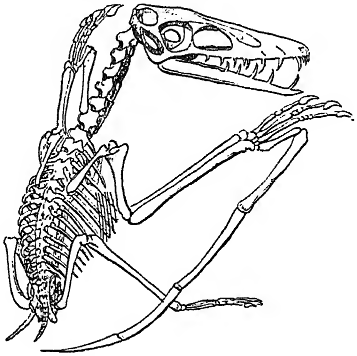

Fig. 433.—Jurassic Pterosaur. Scaphognathus crassirostris, Goldf. (Middle Oolite).

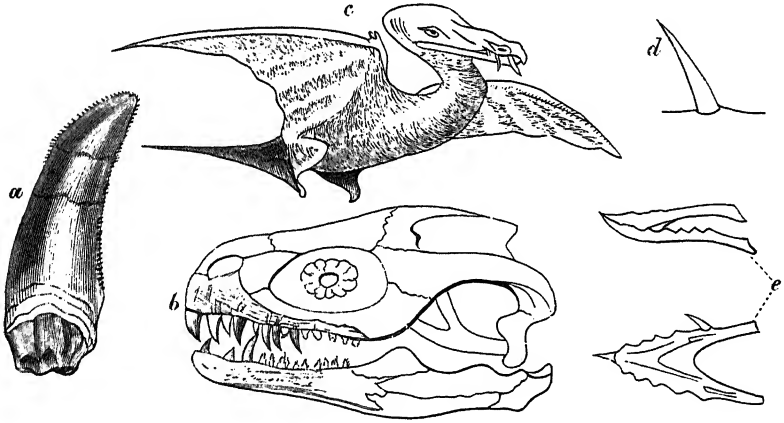

Fig. 434.—Jurassic Deinosaur and Pterosaur.
a, Megalosaurus Bucklandi (Meyer), tooth (½); *b*, Megalosaurus, restoration of head, after Owen ($\frac{1}{20}$); *c*, Rhamphocephalus Bucklandi (Goldf.), restoration, after Phillips (compare Fig. 437); *d*, Do. tooth (nat. size); *e*, Do. jaw (½).

especially by long anterior and short hinder teeth, and by the length of its tail; *Rhamphorhynchus* (Figs. 435-437), also possessing a long tail,

[1] See Marsh on wings of Pterodactyles, *Amer. Journ. Sci.* April 1882. The remarkable specimen of *Rhamphorhynchus* (*R. Munsteri*) from the Solenhofen Slate, described by this author (Figs. 435-437), possessed a long tail, the last sixteen short vertebræ of which supported a peculiar caudal membrane which, kept in an upright position by flexible spines, must have been an efficient instrument for steering the flight of the creature. The three figures which illustrate this structure were supplied by the late Professor Marsh.

with a caudal membrane and having formidable jaws, which may have terminated in a horny beak; *Scaphognathus*, with a massive skull in which the teeth stretch along the whole length; *Rhamphocephalus* and *Dorygnathus*. These strange harpy-like creatures were able to fly, to

Fig. 437.—Jurassic Pterosaur.
Rhamphorhynchus phyllurus, Marsh (Munsteri, Goldf.) (¼). The animal lies upon its back, and the under surface of the wing-membrane is exposed. The caudal membrane is shown of nat. size in Fig. 436.

shuffle on land, or perch on rocks, perhaps even to dive in search of their prey. The long slender teeth which some of them possessed probably indicate that the creatures lived on fish. Lastly, the most colossal living beings of Mesozoic time, and, indeed, so far as we know, of any time, belonged to the ancient order of Deinosaurs, which then attained their maximum

development. In these animals, which appeared in the earliest Mesozoic ages, ordinary reptilian characters (as already remarked) were united to others, particularly in the hinder part of the skeleton, like those of birds. It was during the Jurassic period that the Deinosaurs reached their culmination in size, variety, and abundance. The most important European Jurassic genera are *Compsognathus*, *Megalosaurus* (Fig. 434), and *Cetiosaurus*. In the little *Compsognathus*, from the Solenhofen Limestone, the bird-like affinities are strikingly exhibited, as it possessed a long neck, small head, and long hind limbs on which it must have hopped or walked. The *Megalosaurus* of the Stonesfield Slate is estimated to have had a length of 25 feet, and to have weighed two or three tons. It frequented the shores of the lagoons, walking probably on its massive hind legs, and feeding on the mollusks, fishes, and perhaps the small mammals of the district. Still more gigantic was the *Cetiosaurus*, which, according to Phillips, probably reached, when standing, a height of not less than 10 feet and a length of 50 feet. It seems to have been a marsh-loving or river-side animal, living on the ferns, cycads, and conifers among which it dwelt.[1]

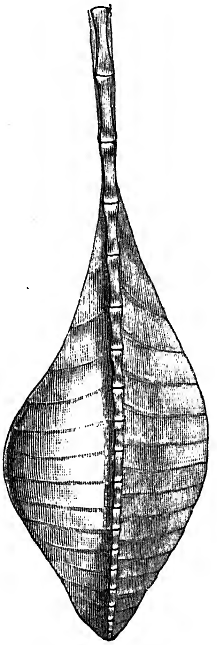

Fig. 436.—Jurassic Pterosaur. Rhamphorhynchus phyllurus, Marsh (Münsteri, Goldf.). Caudal extremity (nat. size).

But these monsters of the Old World were surpassed in dimensions by some discovered in the Jurassic formations of Colorado. Of these, *Brontosaurus* was distinguished by its relatively short body, long neck and tail, and remarkably small head. Its legs and feet were massive, with solid bones, and it made footprints each measuring about a square yard in area. Its length is estimated at 50 feet or more, and its weight, when alive, at more than 20 tons. In habit it was more or less amphibious, probably feeding on aquatic plants or other succulent vegetation. The small head and brain and slender neural cord indicate a stupid, slow-moving reptile.[2] *Stegosaurus* had a remarkably small skull with one of the smallest brains in any known vertebrate, short massive jaws, very short, powerful fore-limbs, and comparatively long and slender hind-limbs. But its most singular character was the possession of numerous dermal spines, some of great size and power, and many bony plates of various sizes and shapes, some of them more than 3 feet in diameter. Thus armed as well as protected, it must have been one of the most uncouth monsters that haunted the waters of the time. Yet it was itself herbivorous, and appears to have been more or less aquatic in habit. The most colossal

[1] Restorations of some of these antique types of life were made by Marsh, *Amer. Journ. Sci.* l. (1895) p. 409 *seq.*, and *Geol. Mag.* (1896), p. 1 *seq.*

[2] Marsh, *Amer. Journ. Sci.* xxvi. (1883), p. 81. Marsh's latest lists will be found in *Monograph* No. xxvii. (1896) *U.S. G. S.*

of all these forms, and, indeed, the most gigantic creature yet known, was that to which Marsh gave the name of *Atlantosaurus*. It was built on so huge a scale that its femur alone is more than 8 feet high, the corresponding bone of the most gigantic elephant looking like that of a dwarf, when put beside this fossil. The whole length of the animal is supposed to have been not much short of 100 feet, with a height of 30 feet or more. In the same stratum with the bones of *Atlantosaurus* were found those of an allied gigantic animal, *Apatosaurus*, which must have been at least 50 feet long. *Diplodocus* had such weak dentition as to show that the creature was herbivorous, probably living on succulent vegetation. *Morosaurus* was marked by the small size of its head for a body about 40 feet long. Besides these various herbivorous deinosaurs, there were likewise bipedal carnivorous types that preyed upon them. Among these the best known, *Ceratosaurus*, was distinguished by the comparatively large size of its skull, which was armed with a high trenchant horn and powerful cutting

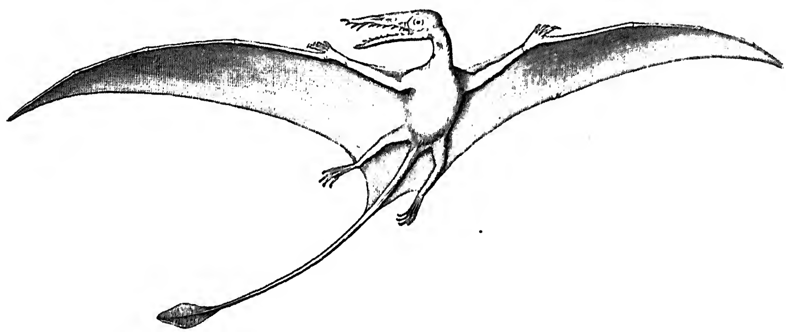

Fig. 437.—Jurassic Pterosaur.
Rhamphorhynchus phyllurus, Marsh (Münsteri) (¼), restored by Marsh.

teeth. The animal was upwards of 20 feet long, and when standing on its massive hind feet must have been some 12 feet high. Contemporaneous with these huge creatures, however, there existed in Jurassic time in North America diminutive forms having such strong avian affinities that their separate bones cannot be distinguished from those of birds. Professor Marsh, who brought these interesting forms to light, regarded them as having been in some cases probably arboreal in habit, with possibly at first no more essential difference from the birds of their time than the absence of feathers.[1] Such were the genera to which he gave the names of *Hallopus* and *Nanosaurus*. *Baptanodon* was a large swimming reptile, most nearly related to *Ichthyosaurus*, but without teeth. *Pantosaurus* is believed to have been a true plesiosaur with teeth,

[1] For Marsh's descriptions of Jurassic Deinosaurs see *Amer. Journ. Sci.* xvi. (1878) p. 411 ; xvii. (1879) p. 86 ; xviii. (1880) ; xix. (1880) p. 253 ; xxi. (1881) p. 417 ; xxii. (1881) p. 340 ; xxiii. (1882) p. 81 ; xxvi. (1883) p. 81 ; xxvii. (1884) p. 161 ; xxxiv. (1887) p. 413 ; xxxvii. (1889) pp. 323, 331 ; xxxix. (1890) p. 415 ; xlii. (1891) p. 179 ; xliv. (1892) p. 347. *Monograph U.S. G. S.* No. xxvii. (1896) p. 481.

and to have been marine in its habits. There was likewise a small crocodile, *Goniopholis* (*Diplosaurus*).

The oldest known bird, *Archæopteryx* (Fig. 438), comes from the Solenhofen Limestone in the Upper Jurassic series—a rock which has been especially prolific in the fauna of the Jurassic period. This interesting organism, which was rather smaller than a crow, united some of the characters of reptiles with those of a true bird. Thus it possessed biconcave vertebræ, a well-ossified sternum, and a long lizard-like tail, each vertebra of which bore a pair of quill-feathers. The three wing-fingers were all free and each ended in a claw, and there appear to

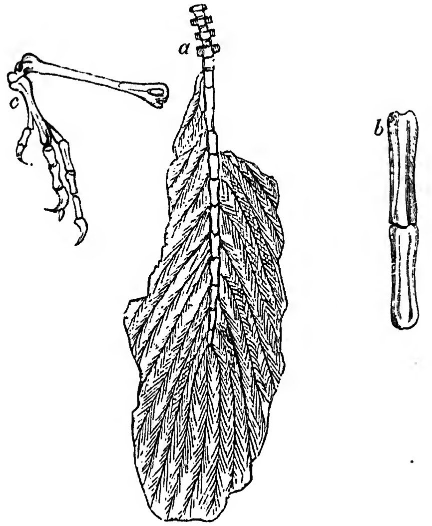

Fig. 438.—Bird (Archæopteryx macrura, Owen)—Solenhofen Limestone (Middle Jurassic). *a*, Tail and Tail-feathers (¼); *b*, caudal vertebræ (nat. size); *c*, foot (¼).

have been four toes to each foot, as in most of our common birds. The jaws carried true teeth, as in the toothed birds found in the Cretaceous rocks of Kansas.[1] Remains of birds have likewise been obtained from the Upper Jurassic rocks (Atlantosaurus-beds) of the Wyoming region in Western America. The best preserved of these, named by Marsh *Laopteryx*, was believed by him to have possessed teeth and biconcave vertebræ.[2]

The most highly organised animals of which the remains have been discovered in the Jurassic system are small forms with monotreme and marsupial affinities. Two horizons in England have furnished these interesting relics—the Stonesfield Slate and the Purbeck beds. The

[1] See Marsh, *Amer. Journ. Sci.* Nov. 1881, p. 337; *Geol. Mag.* 1881, p. 485; Carl Vogt, *Rev. Sci.* Sept. 1879; Seeley, *Geol. Mag.* 1881, pp. 300, 454; W. Dames, *Sitzb. Berlin Akad.* xxxviii. (1882) p. 817; *Geol. Mag.* 1882, p. 566; 1884, p. 418.

[2] *Amer. Journ. Sci.* xxi. (1881) p. 341; also xxii. p. 337.

Stonesfield Slate has yielded the remains of five genera—*Amphitylus*, *Amphilestes*, and *Phascolotherium* (Fig. 439), probably insectivorous, the latter resembling the living American opossums; *Amphitherium*, resembling most closely the Australian *Myrmecobius;* and *Stereognathus*, of which the affinities are uncertain. Higher up in the English Jurassic series another interesting group of mammalian remains has been obtained from the Purbeck beds, whence upwards of twenty species have been exhumed belonging to eleven genera (*Spalacotherium* (*Peralestes*), *Amblotherium*, *Achyrodon*, *Kurtodon*, *Peramus*, *Stylodon*, *Bolodon*, *Triconodon*

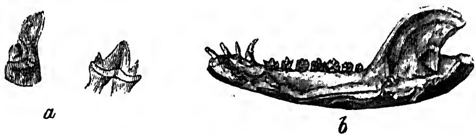

Fig. 439.—Marsupial from the Stonesfield Slate.
Phascolotherium Bucklandi, Broderip: *a*, teeth, magnified; *b*, jaw, nat. size.

(*Triacanthodon*), Fig. 440), of which some appear to have been insectivorous, with their closest living representatives among the Australian phalangers and American opossums, while one, *Plagiaulax*, resembling the Australian kangaroo-rats (*Hypsiprymnus*), was held by Owen to have been a carnivorous form.[1] A still more varied and abundant assemblage of mammalian remains has been exhumed from the Jurassic rocks of the western regions of the United States (p. 1159).

Geographical Distribution.—The Jurassic system covers a vast area in Europe. Beginning at the west, remnants of it occur in the far

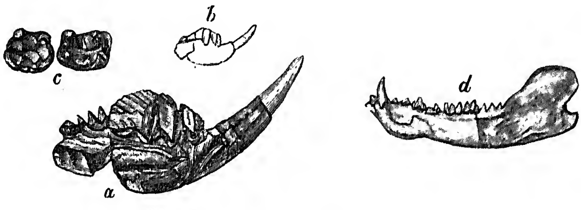

Fig. 440.—Mammals from the Purbeck Beds.
a, Prototherian Jaw of Plagiaulax minor, Falconer (?); *b*, same (nat. size); *c*, molar (?);
d, Marsupial Jaw of Triconodon mordax (Triacanthodon serrula), Owen (nat. size).

north of Scotland. It ranges across England as a broad band from the coasts of Yorkshire to those of Dorset. Crossing the Channel, it encircles with a great ring the Cretaceous and Tertiary basin of the north of France, whence it ranges on the one side southwards down the valleys of the Saone and Rhone, and on the other round the old crystalline nucleus of Auvergne to the Mediterranean. Eastwards, it sweeps through the

[1] See Falconer, *Q. J. G. S.* xiii. 261; xviii. 348; Owen, "Monograph of Mesozoic Mammals," *Palæontograph Soc.* 1871; 'Extinct Mammals of Australia.' 1877; Marsh in the papers cited (*postea*, p. 1159).

Jura Mountains (whence its name is taken) up to the high grounds of Bohemia. It forms part of the outer ridges of the Alps on both sides, rises along the centre of the Apennines, and appears here and there over the Spanish peninsula. Covered by more recent formations, it underlies the great plain of northern Germany, whence it ranges eastwards and occupies large tracts in central and eastern Russia. Neumayr, following up the early generalisation of L. von Buch, maintained that three distinct geographical regions of deposit, marking diversities of climate, can be made out among the Jurassic rocks of Europe.[1] (1) The Mediterranean province, embracing the Pyrenees, Alps, and Carpathians, with all the tracts lying to the south. One of the biological characters of this area was the great abundance of Ammonites belonging to the groups of Heterophylli (*Phylloceras*) and Fimbriati (*Lytoceras*), and the presence of forms of *Terebratula* of the family of *T. diphya* (*janitor*). (2) The central European province, comprising the tracts to the north of the Alpine ridge, including France, England, Germany, and the Baltic countries, and marked by the comparative rarity of the Ammonites just mentioned, which are replaced by others of the genera *Aspidoceras* and *Oppelia*, and by abundant reefs and masses of coral. (3) The boreal or Russian province, comprising the middle and north of Russia, Petschora, Spitzbergen, and Greenland. The life in this area was less varied than in the others; in particular, the widely distributed species of *Oppelia* and *Aspidoceras* of the middle-European province are absent, as well as large masses of corals, showing that in Jurassic times there was a perceptible diminution of temperature towards the north.

Neumayr subsequently extended these three provinces into homoiozoic zones or belts stretching round the globe, and showing the probable distribution of climate and life during Jurassic and early Cretaceous times. (1) The Boreal Zone descends as far as lat. 46° in North America, whence it bends north-eastwards, coming as high as lat. 63° in Scandinavia; but then taking a remarkable bend towards the south-east across Russia, the Kirghiz Steppes and Turkestan into Tibet, about lat. 29° N. and long. 85° E. This curious projection is explained by the fact that the fauna of the Jurassic rocks of Tibet, Kashmir and Nepal, though peculiar, has greater affinities with that of the boreal than with that of more southern zones. The boreal zone is divisible, as far as yet known, into three provinces, the Arctic, Russian and Himalayan. (2) The North Temperate Zone reaches to about lat. 33° in North America. In Europe its limits are more precisely defined. It extends from Lisbon across the Spanish tableland to the west end of the Pyrenees, thence across the south of

[1] Neumayr, "Jura-Studien," *Jahrb. Geol. Reichsanstalt*, 1871, pp. 297, 451; *Verhandl. Geol. Reichsanst.* 1871, p. 165; 1872, p. 54; 1873, p. 288. "Uber climatische Zonen wahrend der Jura- und Kreidezeit," *Denksch. Wien. Akad.* xlvii. (1883), p. 277. 'Die geographische Verbreitung der Juraformation,' *op. cit.* l. (1885), p. 57. In these memoirs the student will find much interesting speculation regarding zoological distribution, organic progress, and vicissitudes of climate during the Jurassic and Neocomian periods. The last memoir contains two suggestive maps of Jurassic geography. Consult also Suess' "Antlitz des Erde."

France and along the north side of the Alps to the north end of the Carpathians, bending southward so as to keep to the north of the Black Sea and Caucasus, and then striking south-eastwards into the Himalaya chain, where it is nearly cut off by the extension of the Boreal Zone just mentioned. In this zone four provinces have been recognised—the middle European, Caspian, Punjab, and Californian. (3) The Equatorial Zone extends southwards to the southern end of Peru, and does not include the extreme southern coasts of South Africa and Australia, which with the remaining part of South America, lie in the South Temperate Zone. In the Equatorial Zone, seven provinces are more or less clearly defined; the Alpine, Mediterranean, Crim-Caucasian, Ethiopian, Columbian, Caribbean (?), and Peruvian. The South Temperate Zone is allowed four provinces: the Chilian, New Zealand (?), Australian, and Cape.

By carefully collecting and collating the evidence furnished by the discovery of Jurassic rocks in all parts of the world, Neumayr believed himself warranted to give a sketch of the probable geographical distribution of sea and land during the Jurassic period, and even to reduce the data to the form of maps. He thought there was sufficient proof of the existence of three great oceans partly coincident with those still existing—the Arctic Ocean, the Pacific Ocean, and the Antarctic Ocean. A central Mediterranean stretched across the narrow part of the American Continent, and traversing what is now the North Atlantic, swept all over central and southern Europe, the present Mediterranean Sea, and the north of Africa. It joined the Arctic Ocean in the Russian plain, sent various arms into Asia, and passing across central India stretched southwards to the Antarctic Ocean. A long and wide branch extended between Africa and a supposed mass of land connecting southern Africa, Madagascar, and southern India. The chief terrestrial areas of the period, according to Neumayr, were the African-Brazilian continent, extending across the southern Atlantic; the Chinese-Australian continent, extending from the north of China over the south-east of Asia to Tasmania and New Zealand; the Nearctic continent, extending from south-eastern Greenland and Iceland across the North Atlantic to the Gulf of Mexico; the Scandinavian island, the European Archipelago, consisting of numerous insular tracts dotted over the Jurassic sea from Ireland on the west to southern Russia on the east; the Turanian island, lying to the east of the Caspian; and the Ural island, on the site of the Ural Mountains. But much of this geography rests on slender evidence. One of the most remarkable facts pointed out by Neumayr is the extent of the overlap of upper Jurassic rocks upon lower members of the system. He showed that the Lias was not deposited over an enormous part of the earth's surface, which nevertheless sank beneath the sea wherein later parts of the Jurassic series were laid down.

§ 2. Local Development.

Britain.[1]—The stratigraphical succession of the Jurassic rocks was first worked out in England by William Smith, in whose hands it was made the foundation of stratigraphical geology. The terms adopted by him for the subdivisions he traced across the country have passed into universal use, and, though some of them are uncouth English provincial names, they are as familiar to the geologists of other countries as to those of England.

The Jurassic formations stretch across England in a varying band from the mouth of the Tees to the coast of Dorsetshire. They consist of sands, sandstones, and limestones interstratified with softer clays and shales. Hence they give rise to a characteristic type of scenery,—the more durable and more porous beds standing out as long ridges, sometimes even with low cliffs, while the clays underlie the level spaces between. Arranged in descending order, the following subdivisions of the English Jurassic system are generally recognised :—

Formations or Series.	Groups or Stages.	Sub-groups or Sub-stages.	Maximum thicknesses Feet.
IV. Upper or Portland Oolites.	Purbeckian	Upper fresh-water beds; Middle marine beds; Lower fresh-water beds	360
	Portlandian	Portland Stone	70
		Portland Sands	150
	Kimeridgian	Kimeridge Clay	600
III. Middle or Oxford Oolites.	Corallian	Coral Rag, Coralline Oolite, and Calcareous Grit	250
	Oxfordian	Oxford Clay and Kellaways Rock	600
II. Lower Oolites.	Bathonian (Great or Bath Oolite group.)	Cornbrash. This forms a persistent band at the top of the lower or variable (marine and estuarine) group	25
		Forest Marble and Bradford Clay	160
		Great or Bath Oolite, with Stonesfield Slate	130
	Fullonian	Fuller's Earth	150
	Bajocian (Inferior Oolite)	Cheltenham beds (thick estuarine series of Yorkshire, representing the whole succession up to the base of the Cornbrash)	270
		Northampton Sands ("Dogger" of Yorkshire)	40
		Midford Sands (passage beds)	
I. Lias.	Upper Lias		70 to 200
	Middle Lias		60 to 345
	Lower Lias		485 to 960

[1] Of British Jurassic rocks the student will find the fullest account in the Geological Survey Monograph on these rocks in England in five volumes, viz., C. Fox-Strangways, 'Yorkshire,' 1892, 2 vols. H. B. Woodward; 'England and Wales, Yorkshire excepted,' 3 vols. 1893-95. Reference should also be made to previous descriptions, especially to Phillips' 'Geology of Oxford and the Thames Valley'; Tate and Blake's 'Yorkshire Lias' (1876); Hudleston's "Yorkshire Oolites," in *Geol. Mag.* 1880-84, and *Proc. Geol. Assoc.* vols. iii. to v.; R. Etheridge, Presidential Address, *Q. J. G. S.* 1882; Woodward's 'Geology of England and Wales'; S. S. Buckman, *Q. J. G. S.* xlv. (1889); xlvi. (1890); xlix. (1893); li. (1895); liii. (1897); lvii. (1901), and to numerous *Sheet Memoirs* of the Geological Survey relating to the districts of the country where the Jurassic rocks are exposed; such as "The Geology of Cheltenham" by E. Hull, and "The Geology of Rutland" by J. W. Judd. The fossils of the different formations have been copiously discussed in the Memoirs of the Palæontographical Society, as in Morris and Lycett's 'Mollusca from

Although these names appear in tabular order, as expressive of what is the predominant or normal succession of strata, considerable differences occur when the rocks are traced across the country, especially in the Lower Oolites. Thus the Inferior Oolite consists of marine limestones and marls in Gloucestershire, but chiefly of massive estuarine sandstones and shales in Yorkshire. These differences help to bring before us some of the geographical features of the British area during the Jurassic period.

I. The LIAS,[1] consists of three stages or groups, well marked by physical and palæontological characters.[2] In the Lower member, numerous thin blue and brown limestones, with partings of dark shale, clay, or marl, are surmounted by other similar argillaceous strata with occasional nodular limestone bands. The Middle Lias consists of argillaceous and ferruginous limestones (Marlstone) with underlying micaceous sands and clays. In some of the midland counties, but more especially in Yorkshire, this subdivision is remarkable for containing a thick series of beds of earthy carbonate of iron (Ironstone series), which has been extensively worked in the Cleveland district. The Upper stage is composed of clays and shales with nodules of limestone, surmounted by sandy deposits which are perhaps best classed with the Inferior Oolite. In Yorkshire it consists of about 240 feet of grey and black shale, in the upper part of which lies a dark band full of pyritous "doggers" (ironstone concretions) and blocks of jet, which are extracted for the manufacture of ornaments. This jet appears to have been originally water-logged fragments of coniferous wood.[3]

These three stages are subdivided into the following zones according to distinctive species of Ammonites (Figs. 441-443), though the zones are not so definite in nature as in palæontological lists:[4]—

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the Great Oolite'; Davidson's 'Oolitic and Liassic Brachiopoda'; Wright's 'Oolitic Echinodermata' and 'Lias Ammonites'; Owen's 'Mesozoic Reptiles'; 'Mesozoic Mammals,' 'Wealden and Purbeck Reptiles'; Hudleston's 'British Jurassic Gasteropoda'; Buckman's 'Inferior Oolite Ammonites.' Much information will likewise be obtained from the catalogues published by the Trustees of the Museum, such as the 'Catalogue of the Fossil Reptilia and Amphibia' by R. Lydekker, that of the Fossil Fishes, by A. Smith Woodward, that of the Fossil Cephalopoda by A. H. Foord and G. C. Crick; 'The Jurassic Bryozoa,' by J. W. Gregory; "The Mesozoic Plants — The Jurassic Flora," by A. C. Seward. For the palæontological zones reference should be made to the original memoirs by Oppel ('Die Juraformation Englands, Frankreichs und Deutschlands,' 1856-58) and Quenstedt ('Der Jura,' 1858).

[1] This word, now so familiar in geological literature, was adopted by William Smith who found it given by the Somerset quarrymen to the "layers" of argillaceous limestone forming a part of the series of rocks to which the term is now applied.

[2] The Lias of Yorkshire is fully described by Mr. C. Fox-Strangways in the first volume of the monograph above cited: and that of the rest of England and Wales by Mr. H. B. Woodward in the third volume.

[3] C. Fox-Strangways, *Mem. Geol. Survey*, "Scarborough and Whitby" (1882), p. 21.

[4] Wright on Liassic Ammonites, *Palæontograph. Soc.* and *Q. J. G. S.* xvi. 374; C. H. Day, *op. cit.* xix. p. 278; Etheridge, *op. cit.* xxxviii. (Address). As the zones are not generally defined by lithological features they cannot be satisfactorily mapped. On the maps of the Geological Survey the base of the Middle Lias is perhaps not drawn uniformly at one palæontological horizon; but it generally corresponds with the base of the Margaritatus zone (See Judd, 'Geology of Rutland,' pp. 45, 89). Considerable differences of opinion have arisen as to the application of the modern generic names of the huge family of Ammonites. The terms assigned in this and the succeeding Parts of Book VI. are given on the authority of Mr. H. Woods, Woodwardian Museum, Cambridge, who has been good enough to revise the lists.

Upper Lias.	17.	Zone of Lytoceras jurense.
	16.	,, Dactylioceras commune.
	15.	,, Harpoceras falciferum, H. serpentinus and Hildoceras bifrons.
	14.	,, Dactylioceras annulatum.
Middle Lias.	13.	,, Paltopleuroceras spinatum.
	12.	,, Amaltheus margaritatus.
Lower Lias.	11.	,, Liparoceras Henleyi, Ægoceras capricornu, Deroceras Davœi, and Lytoceras fimbriatum.
	10.	,, Phylloceras ibex.
	9.	,, Ægoceras Jamesoni.
	8.	,, Deroceras armatum.
	7.	,, Caloceras raricostatum.
	6.	,, Oxynoticeras oxynotum.
	5.	,, Arietites obtusus, Arietites (Asteroceras) stellaris, and Ægoceras planicostatum.
	4.	,, Arietites Turneri and Arnioceras semicostatum.
	3.	,, ,, Bucklandi.
	2.	,, Schlotheimia angulata.
	1.	,, Psiloceras planorbe.

resting conformably on the White Lias and *Avicula contorta* beds (p. 1094).

The organic remains of the British Lias now include about 350 genera and more than six times that number of species. The plants comprise leaves and other remains of cycads (*Cycadites*, *Cycadeoidea*, *Ptilozamites*, *Otozamites*), conifers (*Brachyphyllum*, *Pagiophyllum*), ferns (*Clathropteris*, *Lomatopteris*, *Macrotæniopteris*), and mares' tails (*Equisetites*). These fossils serve to indicate the general character of the flora, which seems now to have been mainly cycadaceous and coniferous, and to have presented a great contrast to the lycopodiaceous vegetation of Palæozoic times. The occurrence of land-plants dispersedly throughout the English Lias shows also that the strata, though chiefly marine, were deposited within such short distance from shore, as to receive from time to time leaves, seeds, fruits, twigs, and stems from the land. Further evidence in the same direction is supplied by the numerous insect remains, which have been obtained principally from the *Am. Planorbis*-zone of the Lower Lias. These were, no doubt, blown off the land and fell into shallow water, where they were preserved in the silt on the bottom. The Neuroptera are numerous, and include eight or more species of *Orthophlebia*. The coleopterous forms comprise a number of herbivorous and lignivorous beetles (*Elater*, *Buprestites*, &c.). There were likewise representatives of the neuropterous (*Libellula*, *Heterophlebia*), dipterous (*Asilus*) and orthopterous (*Mesoblattina*, *Blattina*) orders. These relics of insect life are so abundant in some of the calcareous bands that the latter are known as insect-beds.[1] With them are associated remains of terrestrial plants, cyprids, and mollusks, sometimes marine, sometimes apparently brackish-water.

The marine life of the period has been abundantly preserved, so far at least as regards the comparatively shallow and juxta-littoral waters in which the Liassic strata were accumulated.[2] Foraminifera abounded on some of the sea-bottoms, the genera *Cristellaria*, *Marginulina*, *Frondicularia*, *Nodosaria*, *Dentalina*, *Polymorphina*, and *Vaginulina* being the more important. Corals, though on the whole scarce, abound on some horizons, *Astrocœnia*, *Heterastræa*, *Isastræa*, *Montlivaltia*, *Stylastræa*, and *Thecosmilia* being the genera that present the largest number of species. The crinoids were represented by thick growths of *Isocrinus* and *Pentacrinus*. There were brittle-stars, star-fishes, and sea-urchins (*Ophiura*, *Plumaster*, *Luidia*, *Hemipedina*, *Cidaris*,

[1] Brodie, *Proc. Geol. Soc.* 1846, p. 14; *Q. J. G. S.* v. 31; 'History of Fossil Insects,' 1846. See Scudder, *B. U.S. G. S.* No. 71 (1891), pp. 98-236, for a list of all known Mesozoic insects, and references to the authorities for the description of each species.

[2] See R. Tate, "Census of Lias Marine Invertebrata," *Geol. Mag.* viii. p. 4.

Acrosalenia)—all generically distinct from those of the Palæozoic periods. The

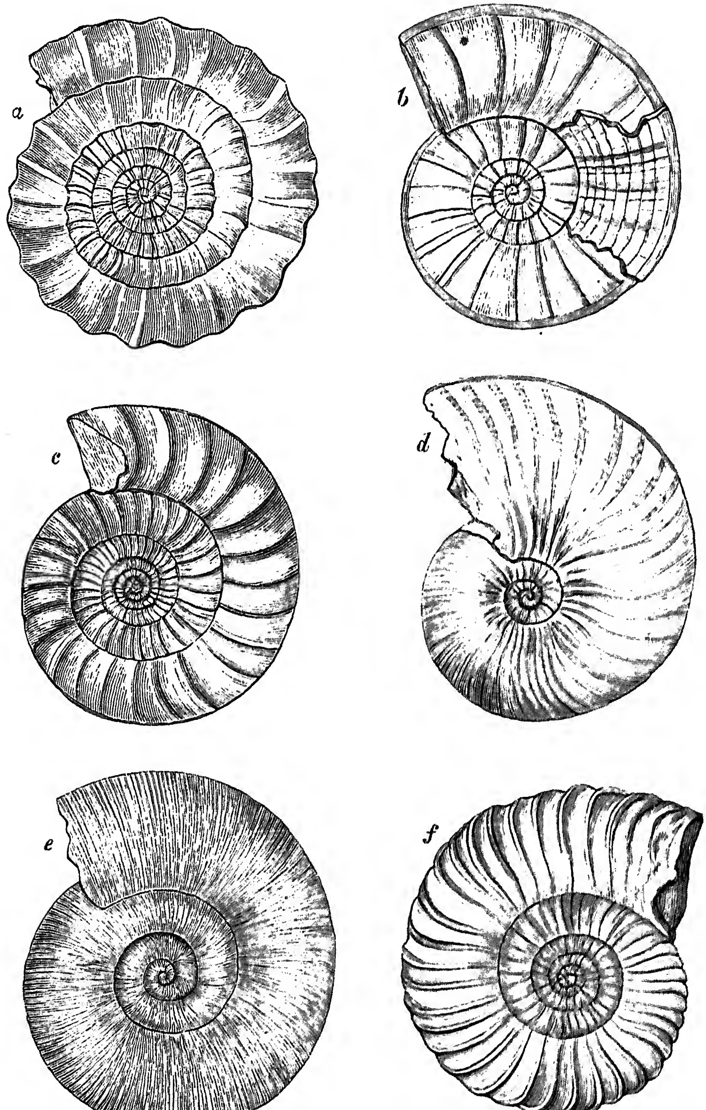


Fig. 441.—Lower Lias Ammonites.

a, Caloceras raricostatum, Zeit. (2/3); *b*, Arietites obtusus, Sby. (1/4); *c*, Arietites Bucklandi, Sby. (1/3); *d*, Oxynoticeras oxynotum, Quenst. (2/3); *e*, Psiloceras planorbe, Sby.; *f*, Schlotheimia angulata, Schloth. (1/3).

annelids were represented by *Serpula* (about a dozen species) and *Ditrupa*. Among the macrourous crustacea, the more frequent genera are *Eryon*, *Glyphæa*, and *Eryma*,

the ostracods being represented more particularly by species of *Bairdia*, *Cythere*, and *Cytherella*.

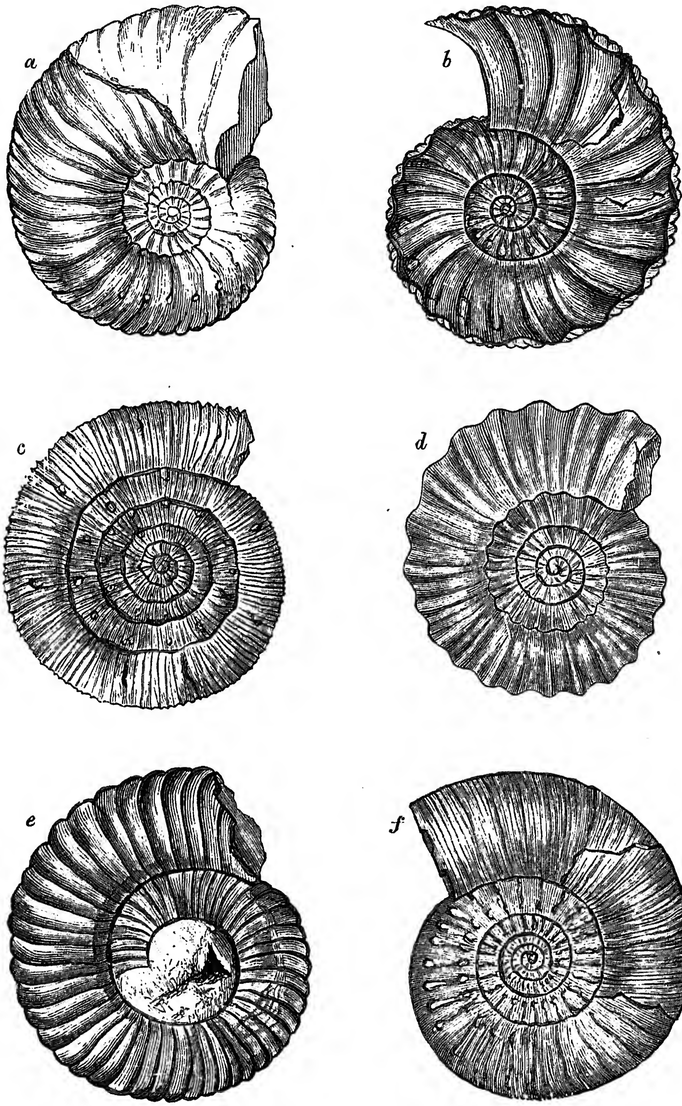


Fig. 442.—Middle and Lower Lias Ammonites.

a, Amaltheus margaritatus, Mont. (½); *b*, Paltopleuroceras spinatum, Brug. (½); *c*, Deroceras Davœi, Sby. (½); *d*, Ægoceras capricornu, Schloth. (½); *e*, Æ. Jamesoni, Sby. (½); *f*, Platypleuroceras brevispinum, Sby. (½).

The brachiopods appear chiefly in the genera *Rhynchonella*, *Waldheimia*, *Spiriferina*, *Thecidium*, and *Terebratula*. *Spiriferina*, the last of the Spirifers, is represented by 11

species, one or two of which ascend to the top of the Upper Lias. With it are associated the last forms of the Strophomenidæ, of which Liassic species from English localities (Fig. 424) have been referred to the genus *Cadomella* (allied to *Leptæna*). Other genera are *Crania, Discina, Lingula, Koninckella, Suessia*, and *Zellania*. Of the lamellibranchs a few of the most characteristic genera are *Pecten, Lima, Avicula, Gryphæa, Gervillia, Ostrea, Plicatula, Modiola, Cardinia, Nuculana* (*Leda*), *Trapezium* (*Cypricardia*), *Astarte, Pleuromya, Hippopodium*, and *Pholadomya*. Gasteropods, though usually rare in such muddy strata as the greater part of the Lias, occur abundantly in some of the calcareous zones. The chief genera are *Actæonina, Amberleya, Bourguetia, Cerithium, Cryptænia, Discohelix, Pleurotomaria* (upwards of 30 species), *Trochus* (40 or more species), *Turbo* (upwards of 30 species), *Turritella*, and *Dentalium*.

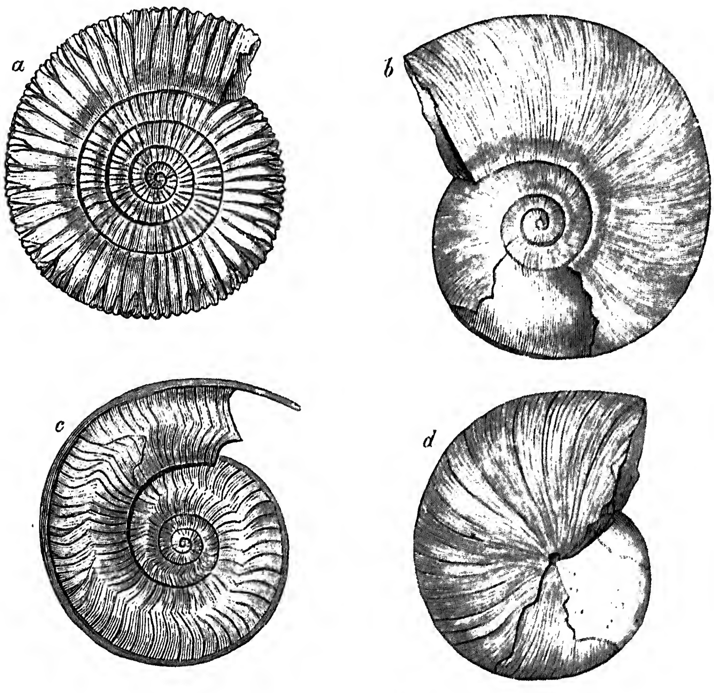


Fig. 443.—Upper Lias Ammonites.
a, Dactylioceras commune, Sby. ($\frac{2}{3}$); *b*, Lytoceras jurense, Zieten ($\frac{1}{12}$); *c*, Harpoceras serpentinum, Reinecke ($\frac{1}{4}$); *d*, Phylloceras heterophyllum, Sby. ($\frac{1}{3}$).

The cephalopods, however, are the most abundant and characteristic shells of the Lias; the families of Ammonites being particularly conspicuous. Many of the English species are the same as those that have been found in the Jurassic series of Germany, and they occupy on the whole the same relative horizons, so that over central and western Europe it has been possible to group the Lias into the various zones given in the foregoing table. The genera *Ægoceras, Arietites*, and *Schlotheimia* are specially prominent in the Lower Lias. The Middle division is more particularly characterised by species of *Amaltheus*, though *Harpoceras, Lytoceras*, and other genera also occur. The Upper Lias is marked by the prominence of *Harpoceras, Hildoceras, Lytoceras, Haugia, Grammoceras, Dumortieria*, &c. Of the genus *Nautilus* about ten

species have been found. The dibranchiate cephalopods are represented by at least 50 species of the genus *Belemnites*, and by *Xiphoteuthis* and *Geoteuthis*.

From the English Lias numerous species of fishes have been obtained. Some of these are known only by their teeth, others by both teeth and spines, while the ganoids frequently have the whole exoskeleton preserved. The selachian genera most commonly met with are *Acrodus* and *Hybodus*. The most frequent ganoids are *Dapedius*, *Pholidophorus*, *Pachycormus*, *Eugnathus*, and *Ptycholepis*. The teleosteans are represented by *Leptolepis*. But undoubtedly the most remarkable palæontological feature in this group of strata is the number and variety of its reptilian remains. The pterosaurs are represented by *Dimorphodon* and *Scaphognathus*, and the deinosaurs by *Scelidosaurus*. Of the ichthyosaurs the Lower Lias, especially in Dorset, has furnished about ten distinct species, and of the plesiosaurs at least a dozen species, besides species of *Eretmosaurus* and *Thaumatosaurus*. In some cases entire skeletons of these creatures have been found with almost every bone in place, and more or less complete specimens of them are to be seen in many public museums. True crocodiles have been met with in the Upper Lias (*Pelagosaurus*, *Steneosaurus*).

The Lias extends continuously across England from the mouth of the Tees to the coast of Dorsetshire. It likewise crosses into South Wales. Interesting patches occur in Shropshire and at Carlisle, far removed from the main mass of the formation. A considerable development of the Lias stretches across the island of Skye, and skirts adjoining tracts of the west of Scotland, where the shore-line of the period is partly traceable; while small portions of the lower division of the formation are exposed on the foreshore of the east of Sutherland, near Dunrobin. In the north of Ireland, also, the characteristic shales appear in several places from under the Chalk escarpment. That these portions of the Jurassic series, together with the *Avicula contorta*-zone below and some of the Chalk above, once extended north-eastwards into the basin of the Clyde is proved by the discovery, made by the Geological Survey, of large masses of fossiliferous strata which have fallen into an extensive volcanic vent of Tertiary age in the Isle of Arran.[1]

II. The LOWER OOLITES[2] lie conformably upon the top of the Lias, with which they are connected by a general similarity of organic remains, and by about 45 species which pass up into them from the Lias. In the south-west and centre of England they chiefly consist of shelly marine limestones, with clays and sandstones; but, traced northwards into Northampton, Rutland, and Lincolnshire, they contain not only marine limestones, but a series of strata indicative of deposit in the estuary of some river descending from the north, for, instead of the abundant cephalopods of the truly marine and typical series, we meet with fresh-water genera such as *Cyrena* and *Unio*, estuarine or marine forms such as *Ostrea* and *Modiola*, thin seams of lignite, thick and valuable deposits of ironstone, and remains of terrestrial plants. These indications of the proximity of land become still more marked in Yorkshire, where the strata (800 feet thick) consist chiefly of sandstones, shales with seams of ironstone and coal, and occasional horizons containing marine shells. It is deserving of notice that the Cornbrash, at the top of the Lower Oolite in the typical Wiltshire district, though rarely 20 feet thick, runs across the country from Devonshire to Lincolnshire and Yorkshire. Thus a distinctly defined series of beds of an estuarine character is in the north homotaxially representative of the marine formations of the south-west. At the close of the Lower Oolitic period the estuary of the northern tract was submerged, and marine deposits were laid down across England.

[1] *Summary of Progress of Geol. Surv.* for 1900; B. N. Peach, W. Gunn, and E. T. Newton, *Q. J. G. S.* lvii. (1901), p. 126.

[2] For an excellent account of these rocks in their typical development see vol. iv. of the Geol. Survey Monograph by Mr. H. B. Woodward, and for the Yorkshire district, vol. i. by Mr. C. Fox-Strangways.

This section of the Jurassic system is subdivided into the following groups of strata and palæontological zones in descending order (Fig. 444):—

Cornbrash . .	Zone of	Macrocephalites macrocephalus, with *Ostrea flabelloides*, *Terebratula intermedia*, *Waldheimia obovata*, *W. lagenalis*.
Forest Marble and Bradford clay	,,	Oppelia? discus, with *Ostrea Sowerbyi*.
Great Oolite and Stonesfield Slate	,,	Perisphinctes arbustigerus, with *Belemnites bessinus* and *Terebratula maxillata*.
Fuller's Earth .	,,	Macrocephalites subcontractus, with *Belemn. parallelus*, *Ostrea acuminata*, and *Waldheimia carinata*.
Inferior Oolite .	,,	Parkinsonia Parkinsoni, Stepheoceras humphriesianum, Ludwigia Murchisonæ, with *Belemn. aalensis*, *Gryphæa sublobata*, *Terebratula globata*, *T. fimbria*, and *Waldheimia carinata*.
Midford Sands (passage - beds into the Lias below)	,,	Lioceras opalinum, *Lytoceras jurense*, with *Rhynchonella cynocephala* and *Terebratula infra-oolitica*.

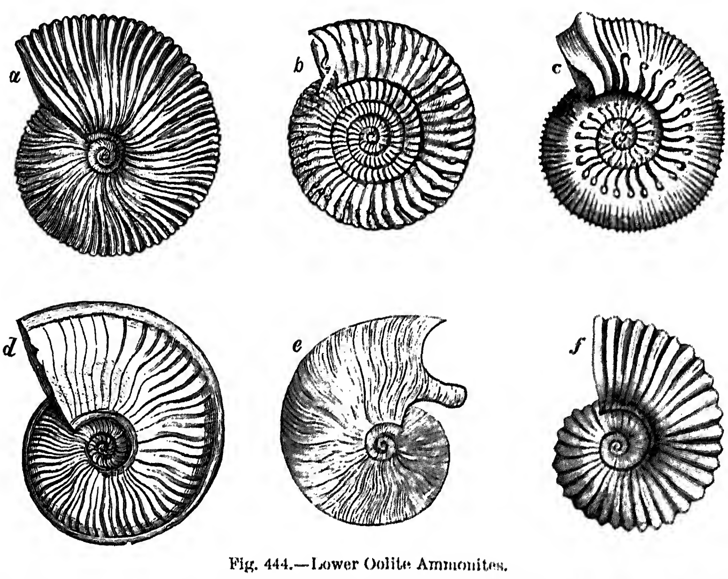


Fig. 444.—Lower Oolite Ammonites.

a, Macrocephalites macrocephalus, Schloth. (⅓); *b*, Parkinsonia Parkinsoni, Sby. (⅓); *c*, Stepheoceras humphriesianum, Sby. (⅓); *d*, Ludwigia Murchisonæ, Sby. (⅓); *e*, Lioceras opalinum, Rein (⅓); *f*, Lytoceras torulosum, Ziet. (⅓).

The English Lower Oolites show considerable local variation in their subdivisons. They are typically developed in the south-western counties, but the limestones and clays pass laterally into sands. The lowest group, that of the Midford Sands, sometimes placed with the Lias, consists of yellow micaceous sands, with some concretionary sandstone and sandy limestone, and ranges from 25 to 200 feet in thickness. A ferruginous limestone at its top in Gloucestershire contains so many Ammonites, Belemnites, and Nautili, that it has been called the "Cephalopoda bed." Two Ammonite zones may be recognised in this group, viz. :—

Zone of Lioceras opalinum.
„ Lytoceras jurense.

Among the other characteristic fossils are *Grammatoceras aalense*, *Pleurolytoceras hircinum*, *Dumortieria radians*, *Haugia variabilis*, *Belemnites compressus*, *B. irregularis*, *Gresslya abducta*, *Trigonia Ramsayi*, *Gervillia Hartmanni*, *Rhynchonella cynocephala*.

The Inferior Oolite (Bajocian)[1] attains its maximum development in the neighbourhood of Cheltenham, where it has a thickness of 264 feet, and consists of calcareous freestone and ragstone or grit.[2] It presents a tolerably copious suite of invertebrate remains, which resemble generically those of the Lias. The corals include species of *Isastræa*, *Montlivaltia*, and other genera. The crinoids are represented by *Pentacrinus*, *Apiocrinus*, &c.; the star-fishes by species of *Astropecten*, *Solaster*, and *Stellaster?*; the sea-urchins by species of *Acrosalenia*, *Cidaris*, *Clypeus*, *Nucleolites* (*Echinobrissus*), *Hemicidaris*, *Hemipedina*, *Pseudodiadema*, *Pygaster*, *Stomechinus*, &c. The predominance of *Rhynchonella*, *Waldheimia*, and *Terebratula* over the rest of the brachiopods becomes still more marked. *Arca*, *Astarte*, *Avicula*, *Gervillia*, *Gryphæa*, *Lima* (upwards of 40 species), *Modiola*, *Pleuromya*, *Ostrea*, *Pecten* (upwards of 40 species), *Pholadomya*, *Tancredia*, and *Trigonia* (60 species) are the most common genera of lamellibranchs. The gasteropods are abundant, especially in the genera *Actæonina*, *Alaria* (more than 30 species), *Bourguetia*, *Cerithium* (upwards of 40 species), *Natica*, *Nerinæa* (more than 40 species), *Pleurotomaria* (between 30 and 40 species), *Pseudomelania*, *Trochus*, *Turbo*. The cephalopoda, as in the Lias, continue to be abundant and to furnish a valuable basis for the stratigraphical subdivision of the strata. Nearly 200 species of Ammonites have been obtained from this formation, and from these it has been subdivided into the following palæontological zones in descending order:[3]—

Zone of Parkinsonia Parkinsoni, with *Oppelia subradiata*, *Terebratula globata*, *Rhynchonella subtetrahedra*, &c.
Zone of Stepheoceras humphriesianum, *Cœloceras Blagdeni*, *Perisphinctes Martinsii*, *Waldheimia carinata*, &c.
Zone of Ludwigia Murchisonæ, with sub-zone of *Sonninia Sowerbyi* in upper part, *Lioceras concavum*, *Terebratula fimbria*, *T. simplex*, *T. plicata*, &c.

The component strata of the group are subject to great variations in thickness and lithological character. The thick marine series of Cheltenham is reduced, in a distance of 30 or 40 miles, to a thickness of a few feet. The limestones pass into sandy strata, so that in parts of Northamptonshire the whole of the formations between the Upper Lias Clay and the Great Oolite consist of sands with beds of ironstone, known as the Northampton Sand. The higher portions of the sandy series contain estuarine shells (*Cyrena*) and remains of terrestrial plants. In Yorkshire the Great Oolite series disappears (unless its upper part is represented there by the "Upper Estuarine series"), while the Inferior Oolites swell out into a great thickness and are composed of the following subdivisions in descending order:[4]—

[1] So named by D'Orbigny in 1849 from Bayeux in Calvados, where the formation is well developed.

[2] This subdivision of the system has recently been treated in great detail by Mr. Buckman in the series of papers in the *Q. J. G. S.* cited on p. 1131.

[3] On the Ammonites of these zones, see S. S. Buckman, *Q. J. G. S.* (1881), p. 588.

[4] Phillips' 'Geology of Yorkshire.' Hudleston, *Geol. Mag.* (1880), p. 246, (1882), p. 146; *Proc. Geol. Assoc.* iii. iv. v. C. Fox-Strangways, "Geology of Scarborough and Whitby," *Mem. Geol. Surv.* (1882), and vols. i. and ii. of the 'The Jurassic Rocks of Britain.'

Yorkshire development of the Inferior Oolite or "Bajocian."

	Feet.
Upper Estuarine series, shales and sandstones resting on a thick sandstone (Moor Grit) . . . . more than	200
Scarborough or Grey Limestone series, consisting of grey calcareous and siliceous bands with shaly partings (*Belemn. giganteus*, *Cœloceras subcoronatum*, *C. Blagdeni*, &c.)	3–100
Middle Estuarine series, chiefly shales, with three or four beds of sandstone full of plant-remains. This is the chief coal-bearing zone of the Lower Oolites. A few thin coal-seams occur, only two of which have been found worth working; none of them exceed 18 inches or 2 feet in thickness	50–100
Millepore bed, a ferruginous or calcareous grit passing into a sandy limestone (*Sonninia Sowerbyi*)	10–40
Lower Estuarine series, consisting of an upper group of false-bedded ferruginous sandstones with carbonaceous matter, separated by some ironstone bands from a lower group of carbonaceous shales and sandstones with thin coal-seams	300
Dogger—ferruginous sandstone and sandy ironstone passing down into the "Jurensis-beds" (Midford Sands with *Lytoceras jurense*), *Ceromya bajociana*, *Ludwigia Murchisonæ*, *Grammoceras aalense*, &c.	

A tolerably abundant fossil flora has been obtained from these Yorkshire beds.[1] With the exception of a few littoral fucoids, all the plants are of terrestrial forms. Among them are more than 50 species of ferns (*Cladophlebis*, *Coniopteris*, *Sphenopteris*, *Dictyophyllum*, and *Tæniopteris* being characteristic). Next in abundance come the cycads, of which above 20 species are known (*Otozamites*, *Williamsonia*, *Nilssonia*). The ginkgos are represented by several species of *Ginkgo*, *Baiera*, and *Beania*. Coniferous remains are not infrequent in the form of stems or fragments of wood, as well as in occasional twigs with attached leaves (*Araucarites*, *Brachyphyllum*, *Cheirolepis*, *Pagiophyllum*, *Cryptomerites*, *Taxites*).

The Fuller's Earth or Fullonian group is an argillaceous deposit which was distinguished under this name by William Smith, 1799. It extends from Dorsetshire to the neighbourhood of Bath and Cheltenham, and attains a maximum depth of nearly 150 feet, but dies out in Oxfordshire, and is absent in the eastern and north-eastern counties. Among its more abundant fossils are *Perisphinctes arbustigerus*, *Macrocephalites subcontractus*, *Goniomya literata*, *Ostrea acuminata*, *Rhynchonella varians*, and *Waldheimia ornithocephala ;* but most of its fossils occur also in the Great and Inferior Oolite. The conditions for marine life over the muddy bottom on which this deposit was laid down would appear to have been unfavourable. Thus few gasteropods are known from the Fuller's Earth, and most of the organic remains occur in the harder, more calcareous bands of "stone" or "rock." The palæontological characters of this group are intermediate between those of the Bajocian and Bathonian groups. The strata are comprised in the zones of *Perisph. arbustigerus* and *Macroceph. subcontractus*. Beds of economic fuller's earth are worked at Midford and Wellow near Bath ; their detergent properties are due to physical characters rather than chemical composition.

The Great Oolite (Bathonian[2]), between Dorset and Somerset on the west and Oxfordshire on the east, consists of five sub-groups of strata : (*a*) at the base, thin-bedded limestones with sands, known as the Stonesfield Slate ; (*b*) shelly and yellow or cream-coloured, often oolitic limestones, with partings of marl or clay—the Great Oolite proper, comprising the famous freestone of Bath ; (*c*) pale earthy white limestones and false-bedded oolites forming the upper "Ragstones" of Bath ; (*d*) an exceedingly variable series of shelly oolitic and flaggy limestones, with clays and shales below and above. The underlying clays form the "Bradford Clay" ; the central calcareous zone is

[1] The best account of these plants will be found in Mr. Seward's essay on the Jurassic flora of the Yorkshire coast, published in the Catalogue of Mesozoic Plants in the British Museum, 1900.

[2] From Bath, the typical district for the formation.

the so-called "Forest Marble"; (*e*) an uppermost persistent band of tough irregular layers of earthy shelly limestone known as "Cornbrash." These subdivisions, except the last-named, cease to be satisfactorily recognisable as they are followed towards the east and north-east. The Forest Marble dwindles away in a north-easterly direction, and has not been recognised in the east of Oxfordshire. It appears to be represented in Bedfordshire, Northamptonshire, and Lincolnshire, by the "Great Oolite Clays" of that district. The Cornbrash, however, is remarkably persistent, retaining on the whole its lithological and palæontological characters from the south-west of England to the district of the Humber. The limestones of the middle sub-group can be traced from Bradford-on-Avon to Lincolnshire. The lower sub-group, including the Stonesfield Slate, is locally developed in parts of Gloucestershire and Oxfordshire, and passes into the "Upper Estuarine series" of the Midland counties.[1]

The fossils of the Bathonian group, as developed in England, show the wide range which might be expected from the variety of geographical conditions under which the strata were deposited. Those of the Stonesfield Slate possess a high geological interest. Among them are about a dozen species of ferns, the genera *Cladophlebis*, *Sphenopteris*, and *Tæniopteris* being still the prevalent forms. The cycads are chiefly species of *Williamsonia* and the conifers of *Brachyphyllum*. With these drifted fragments of a terrestrial vegetation there occur remains of beetles (*Blapsidium*, *Buprestis*, *Curculionites*), dragon-flies, and other insects which had been blown or washed off the land. The waters were tenanted by a few brachiopods (*Rhynchonella concinna* and *Terebratula*), by lamellibranchs (*Gervillia acuta*, *Lima* (four species), *Modiola imbricata*, *Pecten annulatus*, *P. lens*, *P. vagans*, *Trigonia impressa*), by gasteropods (*Natica*, *Nerita*, *Patella*, *Trochus*, &c.), by a few ammonites (*Oppelia discus*, *Perisphinctes gracilis*) and belemnites (*B. aripistillum*, *B. bessinus*), and by elasmobranch and ganoid fishes, of which more than 40 species are known (*Ceratodus*, *Ganodus*, *Hybodus*, *Lepidotus*, *Mesodon*, *Strophodus*, &c.). The reptiles comprise representatives of turtles, also species of *Cimoliosaurus*, *Steneosaurus*, *Teleosaurus*, *Megalosaurus*, and *Rhamphocephalus*. But the most important organic relics from this geological horizon are the marsupial-like mammalia already referred to—*Amphilestes*, *Amphitherium*, *Amphitylus*, *Phascolotherium*, and the more doubtful *Stereognathus*.

The fauna of the Great Oolite proper is distinguished, among other characteristics, by the number and variety of its corals (including the genera *Isastræa*, *Thamnastræa*, *Phyllocœnia* (*Adelastræa*), *Chorisastræa*, *Cryptocœnia*, *Cyathophora*, *Montlivaltia*, &c.). The echinoderms, which rank next to the ammonites in stratigraphical value, are well represented. Among the regular echinoids the most frequent forms are *Hemicidaris*, *Acrosalenia*, *Pseudodiadema*, and *Cidaris*. The irregular echinoids are represented by species of *Nucleolites*, *Clypeus*, *Pygurus*, &c.; the asteroids by *Astropecten* and *Solaster*; the crinoids by *Pentacrinus*, *Apiocrinus* (specially characteristic of the Bradford Clay), and *Millericrinus*. Macrourous crustacea (*Eryma*, *Eryon*, *Glyphæa*) are met with, and likewise brachyourous forms (*Palæinachus*, *Prosopon*). Ostracods abound in the Fuller's Earth, the genera *Cythere* and *Cytheridea* (upwards of 40 species) being specially prominent. Polyzoa are abundant (*Diastopora*, *Entalophora*, *Idmonea*, *Stomatopora*, *Heteropora*). The brachiopods are repesented by species of *Terebratula*, *Rhynchonella*, *Waldheimia*, *Terebratella*, *Crania*, &c. Of the whole British Jurassic lamellibranchs, more than half the genera, and about one-fifth of the species, are found in the Great Oolite. Specially conspicuous are the genera *Pecten*, *Lima*, *Ostrea*, *Avicula*, *Astarte*, *Modiola*, *Pholadomya*, *Trigonia*, *Cardium*, *Arca*, *Tancredia*. The characteristic gasteropods of the Great Oolite include *Natica*, *Nerinæa*, *Nerita*, *Purpuroidea*, *Patella*. Species of ammonite characteristic of the Great Oolite are *Perisphinctes arbustigerus*, *Oppelia discus* (passes to Cornbrash), *Perisphinctes gracilis*, *Macrocephalites subcontractus*, and *Oppelia Waterhousei*. Characteristic likewise are *Nautilus Baberi*, *N. dispansus*,

[1] Judd, 'Geology of Rutland." *Mem. Geol. Surv.*

Belemnites aripistillum, and *B. bessinus*. Of the fishes, the genera most abundant in species are *Mesodon*, *Asteracanthus*, *Hybodus*, *Strophodus*, *Ganodus*, *Ischyodus*, &c. The reptilian remains include the crocodilians *Teleosaurus* and *Steneosaurus*, the pterosaur *Rhamphocephalus*, and the deinosaurs *Megalosaurus*, *Cetiosaurus*, and *Cardiodon*.

The Forest Marble varies greatly in thickness and lithological character. Near Sherborne in Dorsetshire it is 130 feet thick, but it rapidly diminishes northwards, and in Oxfordshire is sometimes only 12 or 15 feet thick. It lies sometimes on the Great Oolite, sometimes on the Fuller's Earth. Its lower portion near Bradford-on-Avon is a grey marly clay with thin layers of tough limestone and calcareous sandstone about 10 feet thick, and this argillaceous band has been separately designated the Bradford Clay. The Forest Marble contains a much diminished fauna. Among the forms characteristic of it are *Apiocrinus Parkinsoni*, *Waldheimia digona*, *Terebratula maxillata*, *Rhynchonella concinna*, *Pecten annulatus*, *Ostrea Sowerbyi*, *Lima cardiiformis*. The Bradford Clay of Wiltshire has long been well known for its pear-encrinites (*Apiocrinus Parkinsoni*), which are found at the bottom of the clay with their base attached to the top of the Great Oolite limestone.

The Cornbrash (an old agricultural term adopted by W. Smith) consists of earthy limestones, which when freshly broken are blue and compact, but which under the influence of the weather break up into rubbly material and make good corn-land. It varies from 10 to 25 feet in thickness, yet in spite of this insignificant development it is one of the most persistent bands in the English Jurassic system. It is rich in echinoderms, lamellibranchs, and gasteropods. Among its common and characteristic species are *Oppelia? discus*, *Macrocephalites macrocephalus*, which ranges up into the Kellaways Rock and Oxford Clay, *Nucleolites clunicularis*, *Holectypus depressus*, *Acrosalenia hemicidaroides*, *Waldheimia lagenalis*, *Ostrea flabelloides*, *Pecten vagans*, *Pleuromya securiformis*, *Lima duplicata*, *Homomya gibbosa*, *Gresslya peregrina*, *Pseudomonotis echinata*.[1]

The Great Oolite series in the north-east of Scotland consists mainly of sandstones and shales, with some coal-seams which were formerly worked at Brora in Sutherland. In Skye and Raasay the formation consists of a very thick estuarine series, with abundant oysters, Trigonias, Anomias, Cyrenas, Hydrobias, Cyprids, and remains of land-plants.

The Middle or Oxford Oolites are composed of two distinct groups: (1) the Oxfordian, and (2) the Corallian, each of which is further subdivided into groups of strata and palæontological zones as under (Fig. 445):

Corallian.	Upper.	Upper Calcareous Grit, Upper Coral Rag and Ironstone . Coral Rag and Coralline Oolite .	Zone of *Perisphinctes plicatilis*.
	Lower.	Lower Calcareous Grit . .	„ *Aspidoceras perarmatum*.
Oxfordian.	Oxford Clay.	Clays with septaria and ironstone nodules . . . Clays with pyritous fossils (sub-zone of *Quenstedtoceras Lamberti*)	„ *Cardioceras cordatum*.
		Shales with pyritous fossils (sub-zone of *Amm.* [*Cosmoceras*] *Jason*)	„ *Cosmoceras ornatum*.
	Kellaways Rock.	Alternations of clays and sands with concretionary calcareous sandstone	„ *Kepplerites calloviensis*.
	Kellaways Clay.	Clay containing selenite and poor in fossils . . .	

(1) Oxfordian, divisible into two sub-groups: (*a*) a lower division of calcareous abundantly fossiliferous sandstone with some underlying clay, known, from a place in

[1] Etheridge, *Q. J. G. S.* (1882), Address, p. 202.

Wiltshire, as the Kellaways Beds, whence this subdivision and its equivalents abroad have been distinguished by the name of Callovian. The Kellaways Clay is generally present, varying from 10 to 20 feet in thickness, and though not especially fossiliferous, yields specimens of *Ostrea*, *Waldheimia*, *Rhynchonella varians*, and *Serpula tetragona*. The Kellaways Rock consists of hard, sandy, calcareous, highly fossiliferous material. The Callovian sub-group forms really the basement of the Oxford Clay. Ranging from a few feet to more than 50 feet in thickness, it may be traced from Wiltshire through Bedfordshire to Lincolnshire, and it attains a considerable importance in Yorkshire. It contains about 200 species of fossils, of which one-third are found in lower parts of the Jurassic series, and nearly the same proportion passes upward into higher zones. Among its characteristic forms are *Alaria trifida*, *Avicula ovalis*, *Cardium cognatum*, *Isocardia minima*, *Pholadomya acuticosta*, *Rhynchonella varians*, *Gryphæa bilobata*. The distinctive ammonite of this stage is *Kepplerites calloviensis*, which gives its name to a zone. Numerous other species of ammonites occur, including *Cosmoceras modiolare*, *C. gowerianum*, *Perisphinctes Bakeriæ*, *Cadoceras Koenigi*, *Macrocephalites macrocephalus*, also *Ancyloceras calloviense*, *Nautilus calloviensis*, and *Belemnites Oweni*.[1]

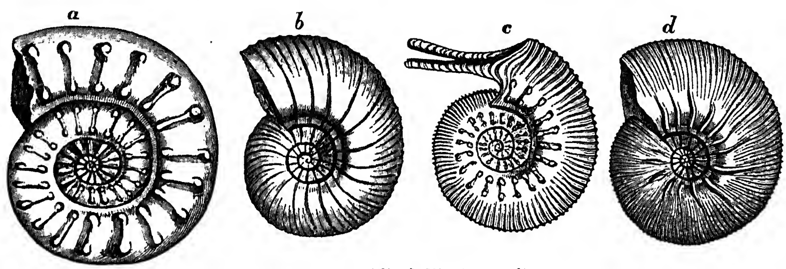


Fig. 445.—Middle Oolite Ammonites.
a, Aspidoceras perarmatum, Sby. ½; *b*, Quenstedtoceras Lamberti, Sby.; *c*, Cosmoceras Jason, Zeit. (⅛); *d*, Kepplerites calloviensis, Sby. (½).

(*b*) The Oxford Clay—so called from the name of the county through which it passes in its course from the coast of Dorsetshire to that of Yorkshire—consists mainly of layers of stiff blue and brown clay, with bands of septaria and occasional layers of earthy limestone, attaining a thickness of from 300 to nearly 600 feet. From the nature of its material and the conditions in which it was deposited, this rock is deficient in some forms of life which were no doubt abundant in neighbouring areas of clearer water. Thus there are no corals, hardly any species of echinoderms, no polyzoa, and less than a dozen species of brachiopods. Some lamellibranchs are abundant, particularly *Gryphæa dilatata* and *Ostrea* (both forming sometimes wide oyster-beds). The lower half of the Clay, containing the zone of *Cosmoceras ornatum*, has yielded small forms of *Gryphæa dilatata*, together with *Cerithium muricatum*, *Avicula inæquivalvis*, *Belemnites Oweni*, and a number of Ammonites—*Reineckia anceps*, *Peltoceras athleta*, *Œkotraustes crenatus*, *Cosmoceras Duncani*, *C. Elizabethæ*, *C. Jason*, *Hecticoceras hecticum*, *Cardioceras Lamberti*, *Quenstedtoceras Mariæ*. The upper part of the deposit, including the zone of *Cardioceras cordatum*, contains large forms of *Gryphæa dilatata*, with *Thracia depressa*, *Serpula vertebralis*, *Belemnites hastatus* (which is found all the way from Dorset to Yorkshire), and various species of Ammonites, *Quenstedtoceras Lamberti*, *Aspidoceras perarmatum*, *Cardioceras vertebrale*. The Oxfordian fishes include the ganoid genera *Aspidorhynchus*, *Eurycormus*, *Hypsocormus*, *Lepidotus*, the

[1] A list of the remarkable assemblage of ammonites in the Kellaways Rock of Yorkshire will be found in Mr. Fox Strangways' Memoir on the Jurassic rocks of that county, p. 277

selachian *Asteracanthus*, *Hybodus*, *Notidanus*, the chimæroid *Brachymylus*, *Ischyodus*, and *Pachymylus*, and the teleostean *Leptolepis*, while the reptiles embrace species of the pterosaur *Rhamphorhynchus*, the deinosaurs *Camptosaurus*, *Cetiosaurus*, *Cryptodraco*, *Megalosaurus*, *Omosaurus*, *Ornithopsis*, and *Sarcolestes*, the crocodiles *Dacosaurus* and *Suchodus*, also a number of species of *Ichthyosaurus*, and of the plesiosaurian genera *Cimoliosaurus*, *Peloneustes*, and *Pliosaurus*.

(2) Corallian, traceable with local modifications from the coast of Dorset to Yorkshire. This group attains in Dorset a thickness of about 200 feet, but diminishes as it is followed into Oxfordshire. In Yorkshire it again swells out to a thickness of 330 feet. The name of the group is derived from the numerous corals which it contains. According to the exhaustive researches of Messrs. Blake and Hudleston,[1] this group when complete consists of the following subdivisions :—

6. Supra-Corallian beds—clays and grits, including the Upper Calcareous Grit of Yorkshire, and the Sandsfoot clays and grits of Weymouth.	Zone of Perisphinctes plicatilis.
5. Coral Rag, a rubbly limestone composed mainly of masses of coral (sub-zone of *Cidaris florigemma*).	
4. Coralline Oolite, a massive limestone in Yorkshire, but dying out southwards and reappearing in the form of marl and thin limestone.	
3. Middle Calcareous Grit, probably peculiar to Yorkshire.	
2. Lower or Hambleton Oolite, not certainly recognised out of Yorkshire.	Zone of Aspidoceras perarmatum.
1. Lower Calcareous Grit.	

The corals are found in their positions of growth, forming massive coral-banks in Yorkshire, Wiltshire, and other districts (*Thamnastræa*, *Isastræa*, *Thecosmilia*, *Rhabdophyllia*, *Montlivaltia*, &c., Fig. 420). Numerous sea-urchins occur in many of the beds, particularly *Cidaris florigemma* (Fig. 422), also *Pygurus*, *Pygaster*, *Hemicidaris*, &c. Brachiopods are comparatively infrequent. The lamellibranchs are still largely represented by species of *Avicula*, *Lima*, *Ostrea*, *Pecten*, and *Gryphæa* (*Ostrea gregaria* being specially numerous). Nearly all the species of gasteropods are peculiar to or characteristic of the Corallian stage. The lower zone (that of *Aspidoceras perarmatum*) is characterised by the occurrence of *Perisphinctes convolutus*, *Oppelia Henrici*, *Cardioceras Sutherlandiæ*, *Perisphinctes? varicostatus*, *Peltoceras Williamsoni*; the upper zone (that of *Perisphinctes plicatilis*) contains some of the same species, but also *Perisphinctes? Berryeri*, *P. cymodoce*, *Hoplites Calisto*, *Cardioceras cawtonense*, *Reineckia decipiens*, *R. mutabilis*, *R. pseudomutabilis*.

IV. The Upper or Portland Oolites bring before us the records of the closing epochs of the long Jurassic period in England. They are divisible into three groups, with subordinate sections and palæontological zones, as shown in the following table :—

3. Purbeckian.	Upper.	Clays, shales, and underlying limestone (Marble Rag) and *Unio*-bed.	
	Middle.	Limestones, including "Upper building-stones," and the band with mammalian remains.	
	Lower.	Marls and limestones with insect-beds and the "Dirt-bed" of Portland.	
2. Portlandian.		Upper Freestones and Cherty beds.	Zone of Perisphinctes giganteus.
		Lower sands and clays.	,, Olcostephanus gigas.

[1] "On the Corallian Rocks of England," *Q. J. G. S.* xxxiii. p. 260.

1. Kimeridgian.	Upper bituminous shales with layers of cement-stone and septaria.	Zone of Perisphinctes biplex, with Aspidoceras longispinum.
	Lower clays and dark shales and cement-stones.	„ Cardioceras (*Amœboceras*) alternans.

(1) Kimeridgian, so named from the clay at the base of the Upper Oolites, well developed at Kimeridge, on the coast of Dorsetshire, whence it is traceable continuously, save where covered by the Chalk, into Yorkshire. It consists of dark bluish-grey shale or clay, which in Dorsetshire is in part bituminous and can be burnt. According to Mr. J. F. Blake it may be subdivided into two sub-groups[1] :—

(*a*) Upper Kimeridgian, consisting of paper-shales, bituminous shales, cement-stone, and clays, characterised by a comparative paucity of species of fossils but an infinity of individuals; perhaps 650 feet thick in Dorsetshire, but thinning away or disappearing in the inland counties. This sub-stage, fairly comparable with the "Virgulian" of foreign authors, contains the zone of *Perisphinctes biplex*, and is marked also by the prominence of *Discina latissima*, which forms a sub-zone in the upper part, while the lower portion of the deposit contains abundant *Exogyra virgula* (Fig. 428).

(*b*) Lower Kimeridgian, blue or sandy clay with calcareous "doggers," representing the "Astartian sub-stage" of foreign geologists. This is the great repository of the fossils of this group. It has a maximum thickness of 400 feet, and embraces the zone of *Cardioceras alternans*, which in its upper part abounds in *Exogyra virgula*, while in its lower part *Ostrea deltoidea* is plentiful enough to form a sub-zone.

Among the more common fossils of the Kimeridge Clay, besides those above named, are numerous foraminifera (*Pulvulina pulchella*, *Robulina Münsteri*), also *Serpula tetragona*, *Exogyra nana*, *Astarte supracorallina*, *Thracia depressa*, *Protocardia striatula* (Fig. 428). Upwards of 20 species of ammonite occur only in this stage; among them are *Cardioceras* (*Amœboceras*) *alternans*, *C. Kapffi*, *Olcostephanus eumelus*, *Reineckia eudoxus*, *R. plicomphalus*, *R. Thurmanni*, *Aspidoceras longispinum*, *A. orthocera*, *A. lallerianum*. Among the belemnites are *B. abbreviatus*, *B. Blainvillei*, *B. excentricus*, *B. nitidus*. The Kimeridge Clay derives its chief palæontological interest from the fact that it has supplied the largest number of the Mesozoic genera and species of reptiles yet found in Britain. The huge deinosaurs are well represented by *Bothriospondylus*, *Cetiosaurus*, *Gigantosaurus*, *Camptosaurus*, *Megalosaurus*, *Omosaurus*; the pterosaurs by *Pterodactylus*; the plesiosaurs by *Cimoliosaurus* (several species), *Peloneustes*, *Thaumatosaurus*, and *Pliosaurus*; the ichthyosaurs by *Ichthyosaurus* (five or more species) and *Ophthalmosaurus*; chelonians by *Thalassemys* and *Pelobatochelys*; and crocodilians by *Geosaurus*, *Metriorhynchus*, and *Steneosaurus*.

In the sea-cliffs of Speeton, Yorkshire, a thick group of clays occurs, the lower part of which contains Kimeridgian fossils, while the higher portions are unmistakably Cretaceous (p. 1183). Traces of a representative of the Kimeridge Clay, and possibly of the Portlandian, above, are found even as far north as the east coast of Cromarty and Sutherland, at Eathie and Helmsdale.

(2) Portlandian, so named from the Isle of Portland, where it is typically developed. This group, resting directly on the Kimeridge Clay, consists of two divisions, the Portland Sand and Portland Stone. At Portland, according to Mr. J. F. Blake, it presents the following succession of beds in descending order :—

Shell limestone (Roach), containing casts of *Cerithium portlandicum* (very abundant), *Isodonta* (*Sowerbya*) *Dukei*, *Natica elegans*, and casts of *Trigonia*.
"Whit-bed"—Oolitic Freestone, the well-known Portland stone (*Perisphinctes giganteus*).
"Curf," another calcareous stone (*Ostrea solitaria*).

[1] J. F. Blake, "On the Kimeridge Clay of England," *Q. J. G. S.* xxxi.

Portland Stone.

- "Base-bed," a building stone like the Whit-bed, but sometimes containing irregular bands of flint.
- Limestone, "Trigonia bed" (*Trigonia gibbosa*, Fig. 428, *Perna mytiloides*).
- Bed (3 feet) consisting of solid flint in the upper and rubbly limestone in the lower flat.
- Band (6 feet) containing numerous flints (*Serpula gordialis*, *Ostrea multiformis*).
- Thick series of layers of flints irregularly spaced (*Perisphinctes bononiensis*, *Trigonia gibbosa*, *T. incurva*).
- Shell-bed abounding in small oysters and serpulæ (*Perisphinctes triplicatus*, *Pleurotomaria rugata*, *P. Rozeti*, *Protocardia dissimilis*, Fig. 428, *Trigonia gibbosa*, *T. incurva*, *Pleuromya tellina*).

Portland Sand (Bononian).

- Stiff blue marl without fossils (12 to 14 feet).
- Liver-coloured marl and sand with nodules and bands of cement stone—26 feet (*Mytilus autissiodorensis*, *Pecten solidus*, *Cyprina implicata*, *Perisphinctes biplex*, &c.)
- Oyster-bed (7 feet) composed of *Exogyra bruntrutana*.
- Yellow sandy beds—10 feet (*Cyprina implicata*, *Arca*).
- Sandy marl (at least 30 feet) passing down into Kimeridge Clay (*Perisphinctes biplex*, *Lima boloniensis*, *Pecten Morini*, *Avicula octavia*, *Trigonia incurva*, *T. muricata*, *T. Pellati*, *Rhynchonella portlandica*, *Discina humphriesiana*).

Among Portlandian fossils a species of coral (*Isastræa oblonga*) occurs; echinoderms are scarce (*Acrosalenia Königi*, &c.), there are also few brachiopods. The most abundant fossils are lamellibranchs, the best represented genera being *Trigonia* (*T. gibbosa*, *T. incurva*, *T. Pellati*), *Pleuromya tellina*, *Pecten lamellosus*, *Ostrea solitaria*, *Cyprina elongata*, *Lucina portlandica*, *Protocardia dissimilis*. The most frequent gasteropod is *Cerithium portlandicum*. The ammonites include some additional forms to those mentioned in the foregoing table. Fish are represented by *Lepidotus*, *Hybodus*, *Ischyodus*, and *Pycnodus*, and some of the older Jurassic reptilian genera (*Ornithopsis*, *Goniopholis*, *Teleosaurus*, *Ichthyosaurus*, *Cimoliasaurus*, *Pliosaurus*) still appear.

(3) Purbeckian.[1]—This group, so named from the Isle of Purbeck, where best developed, is usually connected with the foregoing formations, as the highest zone of the Jurassic series of England. But it is certainly separated from the rest of that series by many peculiarities, which show that it was accumulated at a time when the physical geography and the animal and vegetable life of the region were undergoing a remarkable change. The Portland beds were upraised before the lowest Purbeckian strata were deposited. Hence, a considerable stratigraphical and palæontological break is to be remarked at this line. The sea-floor was converted partly into land, partly into shallow estuaries. The characteristic marine fauna of the Jurassic seas nearly disappeared from the area. Fresh-water and brackish-water forms characterise the great series of strata which reaches up to the Neocomian stage, and might be termed the Purbeck-Wealden series.

Some difference of opinion has arisen as to whether the group of Purbeck strata should be placed in the Jurassic or Cretaceous system. The lithological evidence would rather link them with the former, while the predominant fresh-water nature of their fossils would suggest a connection with the overlying fluviatile Wealden series. Though the invertebrate and vertebrate remains show relations to both systems, the balance of evidence appears to be in favour of Edward Forbes's view that on the whole the Purbeck beds are more naturally grouped with the Jurassic than with the Cretaceous formations. The Wealden series itself is by many palæontologists claimed as properly belonging to the former rather than the latter system. This subject is further discussed at p. 1184.

[1] See more particularly the following Memoirs of the Geological Survey: E. Forbes, "Tertiary Fluvio-marine Formation of the Isle of Wight"; H. W. Bristow, "The Isle of Wight," new edition by C. Reid and A. Strahan; A. Strahan, "The Geology of the Isle of Purbeck and Weymouth."

The Purbeckian group has been divided into three sub-groups. Of these, the lowest (95 to 160 feet) consists of fresh-water limestones and clays, with layers of ancient soil ("dirt beds") containing stumps of the trees which grew in them; the middle comprises 50 to 150 feet of strata with some marine fossils, while the highest (50 to 60 feet) shows a return of fresh-water conditions. Among the indications of the presence of the sea is an oyster-bed (*Ostrea distorta*) 12 feet thick, with *Pecten, Modiola, Avicula, Thracia*, &c. The fresh-water bands contain still living genera of lacustrine and fluviatile shells (*Viviparus, Melanopsis, Planorbis, Physa, Valvata, Unio, Cyrena*). Numerous fishes, chiefly ganoid, but with some selachian and teleostean forms, haunted these Purbeck waters (*Caturus, Histionotus, Lepidotus, Leptolepis, Macrosemius, Mesodon, Microdon, Pleuropholis, Asteracanthus, Hybodus*). Many insects, blown off from the adjacent land, sank and were entombed and preserved in the calcareous mud of the Lower and Middle sub-groups. These include coleopterous (more than 30 genera), orthopterous, hemipterous, neuropterous, and dipterous forms (Fig. 431). Remains of reptiles, including deinosaurs (*Echinodon, Iguanodon, Nuthetes*), crocodiles (*Goniopholis, Nannosuchus, Oweniasuchus, Petrosuchus, Theriosuchus*), plesiosaurs (*Cimoliosaurus*), and numerous chelonians (*Chelone, Hylæochelys, Pleurosternum, Thalassemys, Tretosternum*). The interesting dwarf crocodiles (*Theriosuchus*) are computed to have been only 18 inches long. The most remarkable organisms of this group of strata, however, are the mammalian forms already noticed (p. 1127), which occur almost wholly as lower jaws, in a stratum about 5 inches thick, lying near the base of the Middle Purbeck sub-group, these being the portions of the skeleton that would be most likely first to drop out of floating and decomposing carcases.

The zone of *Belemnites lateralis* in the Speeton Clay of the Yorkshire coast and the Spilsby Sandstone of Lincolnshire, are considered by Professor A. Pavlow and Mr. G. W. Lamplugh to represent in part the Purbeck and Portland beds of the southern districts.[1]

France and the Jura.—The Jurassic system is here symmetrically developed in the form of two great connected rings. The southern ring encloses the crystalline axis of the centre and south; the northern and larger ring encircles the Cretaceous and Tertiary basin and opens towards the Channel, where its separated ends point across to the continuation of the same rocks in England. But the structure of the two districts is exactly opposite, for in the southern area the oldest rocks lie in the centre and the Jurassic strata dip outwards, while in the northern region the youngest formations lie in the centre and the Jurassic beds dip inward below them. Where the two rings unite in the middle of France they send a tongue down to the Bay of Biscay. On the eastern side of the country the Jurassic system is copiously developed, and extends thence eastwards through the Jura Mountains into Germany.

The subdivisions of the Jurassic system in the north and north-west of France belonging to what has been termed the Anglo-Parisian basin, resemble generally those established in England. But in the southern half of the country, and generally in the Mediterranean province, the facies departs considerably both lithologically and palæontologically from the English type, more particularly as regards the Upper Jurassic rocks. The following table gives in descending order a summary of the distribution of the Jurassic system in France:[2]—

[1] *Bull. Soc. Imp. des Nat. Moscou*, 1891. Lamplugh, *Q. J. G. S.* lii. (1896), p. 216.

[2] For a detailed account of the development of the Jurassic rocks of France, see De Lapparent's 'Géologie,' 4th edition (1900), of which the author of the present work has largely availed himself; also A. d'Orbigny's 'Paléontologie Française—Terrains Oolithiques,' 1842-50; D'Archiac, 'Paléontologie de la France,' 1868, and 'Paléontologie Française, continuée par une réunion de Paléontologistes—Terrain Jurassique,' in course of publication; Hébert, 'Les Mers anciennes et leurs Rivages, dans le Bassin de Paris,' 1857 (a most interesting and valuable essay), and numerous papers in *Bull. Soc. Géol. France;*

10. Portlandian, separated into two sub-stages, At the base lie sands and clays, equivalents of the Portland Sands or "Bononian," with *Olcostephanus portlandicus* and *Exogyra virgula*. Higher up come sands and calcareous sandstones corresponding to the Portland Stone, with *Trigonia gibbosa* and *Perisphinctes bononiensis*, while the Purbeckian is marked by species of *Cyrena*, *Corbula*, and *Cypris*. The stage is best developed along the coast near Boulogne-sur-mer, where it is composed of about 250 feet of clays, sands, and sandstones, with *Acrosalenia Koenigi*, *Nucleolites Brodiei*, *Cardium Pellati*, *Trigonia radiata*, *T. gibbosa*, *T. incurva*, *Ostrea expansa*, *Perna Bouchardi*, *Harpagodes* (*Pterocera*) *Oceani*, *Perisphinctes Bleicheri*, *P. bononiensis*, &c. At the top lies a bed of limestone containing *Cyrena Pellati*, and covered by a travertine with *Cypris*, which may represent the Purbeck beds. Far to the south, in Charente, some limestones containing Portlandian fossils are covered by others with *Corbula inflexa*, *Physa*, *Viviparus*, &c., possibly Purbeck. Fresh-water limestones, gypsiferous marls and dolomites (about 200 feet), and containing *Corbula forbesiana*, *Physa wealdiana*, *Valvata helicoides*, *Trigonia gibbosa*, &c., occur in the Jura, round Pontarlier and near Morteau, in the valley of the Doubs.[1]

The Upper Jurassic rocks of southern France, the southern flank of the Alps, and the wide area of the Mediterranean basin, present a facies so different from that which was originally studied in England, northern France, and Germany that much difficulty was for many years experienced in the correlation of the deposits, and much discussion has arisen on the subject. From the researches of Oppel, Benecke, Hébert, and later writers, the true meaning of the southern facies is now better understood. It appears that the formations between the zone of *Perisph. biplex* and *Aspid. longispinum* at the top of the Kimeridgian group and the base of the Cretaceous system are represented in the southern area by a singularly uniform series of limestones, indicative of long unbroken deposition in deeper water, and unvaried by those oscillations and occasional terrestrial conditions which are observable farther north. The name of Tithonian (which is thus homotaxial with Portlandian) was given by Oppel to this more uniform suite of strata, marked by the mixed character of their cephalopods, and by their peculiar perforated brachiopods of the type of *Pygope janitor* (=*Terebratula diphya*).[2] Around Grenoble, the massive limestones resting upon some marls with species belonging to the zone of *Oppelia tenuilobata*, contain *Pygope janitor* associated with *Perisphinctes transitorius*, *Belemnites Pilleti*, *Cidaris glandifera*, *Apiocrinus flexuosus*. In the Basses Cevennes, the limestones attain a thickness of more than 1000 feet. At their base lie marls and marly limestones containing *Macrocephalites macrocephalus*. A band of bluish limestone with bituminous marls (65 feet), belonging to the zone of *Peltoceras bimammatum*, represents the Corallian. Some grey limestones (260 feet), with *Perisphinctes polyplocus*, contain fossils of the zone of *Oppelia tenuilobata*, equivalent to the Sequanian stage (p. 1149). These are succeeded by a massive limestone (330 feet) with *Pygope janitor* and *Perisphinctes transitorius*, and this by a compact white limestone (500-650 feet) with *Terebratula moravica*, *Cidaris glandifera*, corals, &c. At the top lie some limestones (200 feet) with *Pygope diphyoides* and many ammonites (*Perisph. transitorius*, *Haploceras caractheis*, *Hoplites Calisto*, &c.).

9. Kimeridgian (=Kimeridge Clay), divisible in central and northern France into the following sub-stages in descending order :—

(*b*) Virgulian.[3] Zone of *Aspidoceras orthocera*, *Reineckia eudoxus*, and *R. pseudomutabilis*.

Monographs by Loriol, Cotteau, Pellat, Royer, Tombeck, Glangeaud (*Bull. Carte Géol. France*, Nos. 50, 62); Gosselet's 'Esquisse,' cited *ante*, p. 927. J. F. Blake, *Q. J. G. S.* 1881, p. 497, gives a bibliography for N.W. France, and Barrois (*Proc. Geol. Assoc.*) a summary of results for the Boulonnais. For the last-named district consult also Pellat, *B. S. G. F.* viii. (1879); Douvillé et Rigaux, *op. cit.* xix. (1891), p. 819. Rigaux, 'Notice Géologique sur le Bas Boulonnais,' Boulogne-sur-mer, 1892.

[1] On the Portlandian rocks of the Aquitanian basin see Glangeaud, *Bull. Carte Géol. France*, No. 62 (1898).

[2] For a study of the Tithonian fauna see A. Toucas, *B. S. G. F.* xviii. (1890), p. 560.

[3] Named from the abundance of the oyster *Exogyra virgula*.

(*a*) Pterocerian.[1] Zone of *Perisphinctes* (*Pictonia*) *cymodoce*, *Olcostephanus eumelus*, *Oppelia tenuilobata*.

The coast-section near Boulogne-sur-mer exposes a series of clays, sands, and sandstones (180 feet), from which a large series of characteristic fossils has been obtained, and which, as the type section of the "Bononian" beds, indicate a local littoral deposit in the upper part of the Kimeridge Clay. The Virgulian sub-stage consists of clays, sands, and limestones, with abundant *Exogyra virgula*, together with *Harpagodes* (*Aspidoceras*) *orthocera* in the lower part, *A. caletanum* higher up, and *Olcostephanus erinus* at the top. In the French Ardennes, the Pterocerian and Virgulian substages are composed of a succession of marls and limestones, the Pterocerian limestones being marked by *Waldheimia humeralis*, *Malaptera* (*Pterocera*) *ponti*, &c., and the Virgulian marls by immense numbers of *Exogyra virgula*. In the Meuse and Haute Marne, a group of compact limestones, more than 500 feet thick (Calcaires de Barrois), with *Olcostephanus gigas*, &c., represents the Bononian sub-stage. Towards the Jura the Pterocerian sub-stage is well developed, and shows its characteristic fossils; while the Bononian comprises the so-called "Portlandian" limestones of the Jura, its upper part becoming the yellow or red unfossiliferous "Portlandian dolomite." In the department of the Jura, the Pterocerian sub-stage contains a coral-reef, more than 300 feet thick, near Saint Claude, and farther south another occurs at Oyonnax. In the same region, the Virgulian sub-stage, composed of bituminous shales and thin lithographic limestones, has yielded numerous fishes, reptiles, and abundant cycads and ferns. The position of these beds is fixed by the occurrence of the *Exogyra virgula* below them, and of the Bononian limestones with *Nerinæa* and *Olcostephanus gigas* above them. From what was said above under the Portlandian stage, it will be seen that the Kimeridgian appears in a totally different aspect in the Mediterranean basin, being there composed of thick limestones with a mixed assemblage of ammonites, and characterised in the higher parts by the appearance of *Pygope janitor*.

8. Sequanian.—According to recent readjustments of the nomenclature, this stage is equivalent to the upper half of the English Corallian series. It is subdivided into two sub-stages as follows:—

(*b*) Upper or Astartian.[2] Zone of *Perisphinctes Achilles* and *Zeilleria humeralis*.
(*a*) Lower or Rauracian.[3] Zone of *Peltoceras bimammatum*.

The English coralline type of deposit is prolonged far into the continent. It appears in considerable development in the Ardennes, where the limestones, full of corals, and alternating with marls, attain a thickness of 400 to 420 feet. Similar limestones attain a great prominence on the Meuse, where they are more than 450 feet thick, and consist of oolites and corals in their positions of growth. In their lower portions they contain *Hemicidaris crenularis*, *Glypticus hieroglyphicus*, *Cidaris florigemma*, and numerous corals; in their upper part they yield *Diceras arietinum*, *Nerinæa Mandelslohi*, *Cardium corallinum*, *C. sublamellosum*. Again in Yonne this sub-stage presents a coral-reef full of bunches of *Septastræa*, *Montlivaltia*, &c. Farther south-east, in the Swiss Jura, coralliferous zones are intercalated in the oolitic strata. South-westwards, in Burgundy, massive limestones with corals reappear, with lithographic and oolitic limestones. In the district of Besançon, the stage is represented by 130 to 200 feet of coral-limestone with compact and oolitic bands, and sometimes with calcareous marls that abut against the sides of what were formerly coral-reefs. Some horizons in this region are marked by the occurrence of remains of ferns and other land-plants (Saint Mihiel, in Lorraine: Dept. of Indre).

7. Oxfordian and Callovian.—Under these names are included the lower part of the English Corallian group and the whole of the Oxford Clay and Kellaways substage. The strata are subdivided into four sub-stages:—

(*d*) Upper Oxfordian or Argovian. Zone of *Ochetoceras canaliculatum* and *Perisphinctes Martelli*.

[1] From the prevalence of the gasteropod *Pterocera*.

[2] So called from the prevalent genus *Astarte*.

[3] From Rauracie, a name applied to the Jura region.

(*c*) Lower Oxfordian (Neuvizyan). Zone of *Cardioceras cordatum* and *Peltoceras transversarium*.
(*b*) Upper Callovian (Divesian). Zones of *Quenstedtoceras* (*Cardioceras*) *Mariæ*, and *Q. Lamberti* and *Peltoceras athleta*.
(*a*) Lower Callovian. Zone of *Reineckia anceps* and *Stepheoceras* (*Erymnoceras*) *coronatum*, and beneath it the zone of *Cosmoceras gowerianum* and *Macrocephalites macrocephalus*.

The upper part of the Callovian stage is well exposed on the coast of Calvados, between Trouville and Dives, where the Divesian marls and clays attain a thickness of more than 200 feet (*Quenstedtoceras* (*Cardioceras*) *Lamberti*, *Q. Mariæ*, *Peltoceras athleta*, *Cosmoceras Duncani*, *Belemnites hastatus*, *Ostrea gregaria*, *Gryphæa dilatata*), and an upper sub-group of clays with *Cardioceras cordatum*, *C. vertebrale*, *Peltoceras Eugenii*, *Aspidoceras*, *Gryphæa dilatata*, &c., representing the Oxfordian. The two stages, though much reduced in thickness, are clearly recognisable in the Boulonnais. North-eastwards, in the Ardennes, the Callovian stage appears as a pyritous clay (25-30 feet) with oolitic limonite, the Oxfordian as a series of clays, marls, argillaceous sandstone (full of gelatinous silica and locally known as *gaize*) and oolitic ironstone. The iron-ore is worked at Neuvizy, where a large series of fossils has been obtained. Round Poitiers, the Callovian division is upwards of 100 feet thick. Eastwards it dwindles down towards the Jura, but is recognisable there under the Oxfordian pyritous marls (330 feet).

6. Bathonian.—This subdivision comprises the French equivalents of the English Lower Oolites from the Fuller's Earth up to the top of the Cornbrash. Regarded from the point of view of the distribution of its ammonites, it has been subdivided into four zones :—

(*d*) Zone of *Oppelia aspidoides* with *Œcotraustes serrigerus* and *Oppelia* (*Oxynoticeras*) *discus*.
(*c*) „ *Oppelia fusca*, *Morphoceras polymorphum*, and *Pictonia zig-zag*.
(*b*) „ the maximum development of *Parkinsonia Parkinsoni*.
(*a*) „ *Parkinsonia* (*Cosmoceras*) *garantiana*, *P. subfurcata*, and *Cœloceras subcoronatum*.

In Normandy the Bathonian stage continues the type of the south of England. It consists of (*a*) a lower group of strata which at one part are the Port-en-Bessin marls (100 feet or more, with *Belemnites bessinus*, *Morphoceras polymorphum*, *Oppellia fusca*, &c.) and at another, the famous Caen stone, so long used as a building material, and which from its saurian and other remains may be paralleled with the Fuller's Earth and Stonesfield Slate; (*b*) oolitic limestones (Oolithe Miliaire) about 100 feet thick, with *Lucina Bellona*, probably representing the Great Oolite of England; (*c*) granular limestone (Ranville), bryozoan limestone, with some of the fossils of the Bradford Clay and Forest Marble (*Eudesia cardium*, *Dictyothyris coarctata*, *Terebratula flabellum*, *Waldheimia digona*); (*d*) marly limestones and blue clay (Lion-sur-Mer) with *Oxynoticeras Hochstetteri*, *Perisphinctes procerus*, *Eudesia cardium*, *Rhynchonella major*, probably representing the English Cornbrash. In the Ardennes, the Fuller's Earth is represented by some sandy limestones, lumachelles, and granular limestone, with *Ostrea acuminata*, *Parkinsonia Parkinsoni*, *Belemnites giganteus*, &c.; the Great Oolite by a massive limestone (160-200 feet) with *Cardium pes-bovis*, *Purpuroidea minax*, followed by 150-180 feet of limestones, with numerous fossils (*Rhynchonella decorata*, *R. elegantula*, *Ostrea flabelloides*, &c.). The limestones are replaced eastwards by marly and sandy beds. In the Côte-d'Or, the stage is largely developed, and is divided into three sub-stages: (*a*) Lower (115 feet), limestones and marls with zones of *Homomya gibbosa*, *Terebratula Mandelslohi*, *Pholadomya bucardium*; (*b*) Middle (196 feet), white limestones and oolites, with zone of *Perisphinctes arbustigerus*, *Purpuroidea glabra* and echinoderms; (*c*) Upper (82 feet) limestones and marls with *Eudesia cardium*, *Waldheimia digona*, *Pernostrea Pellati*, *Pentacrinus Buvignieri*, and with land-plants in one of the zones. In the south of France the Provençal type of sediments appears in a series of marly limestones (more than 450 feet thick between Aix and Marseilles) with *Perisphinctes arbustigerus*, &c.

5. Bajocian,[1] well developed in the department of Calvados, as the name denotes. Its

[1] From Bayeux in Calvados.

thickness is 60-80 feet, and it consists of: 1, Lower limestone (*Ludwigia Murchisonæ, Lioceras concavum*); 2, limestone with numerous ferruginous oolites, fossils abundant and well preserved (*Parkinsonia garantiana, Cœloceras subcoronatum* (*Amm. humphriesianus*), *Parkinsonia Parkinsoni, Perisphinctes Martiusi, Oppelia subradiata, Belemnites giganteus*, &c.); 3, Upper white oolite with abundant brachiopods, sponges, and urchins (*Belemnites unicanaliculatus, B. bessinus, Parkinsonia Parkinsoni, Terebratula Phillipsi, Stomechinus bigranularis*, &c.). In the French Ardennes, the stage (400 feet) presents a lower group of marls with *Ludwigia Murchisonæ* and many corals, followed by an upper limestone (30-130 feet) with *Cœloceras Blagdeni, Belem. giganteus*, &c. Towards Lorraine, this limestone becomes charged with corals, some parts being true reefs. North of Metz, the stage is mostly limestone, and reaches a thickness of 330 feet. In Burgundy, it is chiefly a crinoidal limestone (100 feet), capping boldly the Liassic marls. In the Jura, it attains a thickness of upwards of 300 feet, and consists chiefly of limestone. In Southern France, it swells out to greater proportions, reaching in Provence a thickness of 600 feet, where it consists of sandy limestones and marls below (*Cancellophycus, Lima heteromorpha*) with a thin overlying limestone abounding in ammonites (*Sonninia Sowerbyi, Sphæroceras Sauzei*), above which comes a mass of calcareous marls. 550 feet thick, seldom containing any other organism than *Pecten Silenus*.

The Lias of France and Switzerland has been subdivided into four stages, of which the uppermost three correspond on the whole with the Upper, Middle, and Lower Lias of England, while the fourth is the equivalent of the basement beds of the English Lias, with perhaps part of the Penarth or Rhætic group. These subdivisions, with their several palæontological zones, are shown in the subjoined table.

Toarcian.	Zone of *Lioceras* (*Harpoceras*) *opalinum* and *Grammoceras* (*Harpoceras*) *aalense*.
	,, *Lytoceras jurense* with *Hammatoceras insigne* and *Grammoceras* (*Harpoceras*) *fallaciosum* (*Ammonites radians*).
	,, *Dactylioceras* (*Cœloceras*) *commune, Cœloceras crassum, Hildoceras* (*Harpoceras*) *bifrons*.
	,, *Harpoceras falciferum* and *Hildoceras* (*Harpoceras*) *bifrons*.
Charmouthian.	Zone of *Paltopleuroceras* (*Amaltheus*) *spinatum*.
	,, *Amaltheus margaritatus* and *Grammoceras* (*Harpoceras*) *normannianum*.
	,, *Deroceras* (*Ægoceras*) *Davoei, Ægoceras capricornu*, and *Lytoceras fimbriatum*.
	,, *Phylloceras ibex* with *Uptonia* (*Ægoceras*) *Jamesoni* at the base and *Deroceras* (*Ægoceras*) *armatum*.
Sinemurian.	Zone of *Ophioceras* (*Arietites*) *varicostatum*, with lower sub-zone of *Oxynoticeras oxynotum*.
	,, *Arietites obtusus*, with *A.* (*Asteroceras*) *stellaris* and *Ægoceras* (*Microderoceras*) *planicostatum*.
	,, *Arietites Turneri*.
	,, *Arietites Bucklandi*, with lower sub-zone of *Arnioceras* (*Arietites*) *semicostatum* (*geometricum*).
Hettangian.	Zone of *Schlotheimia* (*Ægoceras*) *angulata*.
	,, *Psiloceras* (*Ægoceras*) *planorbe*.

4. Toarcian.—This division corresponds closely with the Upper Lias of England. It is well developed in Lorraine, where it is from 330 to 370 feet thick, and consists of a lower series of marls with *Posidonomya*, followed by an upper group of sandstone, oolitic brown ironstone, and overlying micaceous marls. This ironstone, which is marked by the presence of *Lioceras* (*Harpoceras*) *opalinum, Hammatoceras insigne, Belemnites abbreviatus, Gryphæa ferruginea, Trigonia navis*, is largely worked at Longwy, Villerupt, &c., and can be traced from the Ardèche to Luxembourg. In the Ardennes, the stage includes a lower series of marls and clays (300 feet) with *Harpoceras* (*Lioceras*) *serpentinum*, a middle marl containing *Grammoceras* (*Harpoceras*) *radians, Hildoceras bifrons, Cœloceras raquinianum, Belemnites compressus, B. acuarius*, and an upper limonite (Longwy) with *Lioceras* (*Harpoceras*) *opalinum, Grammoceras* (*Harpoceras*) *aalense, Ostrea ferruginea*,

Trigonia navis. In Yonne and Côte-d'Or, it consists of the following members in ascending order:—1, marls with *Posidonomya* and lumachelle with *Harpoceras* (*Lioceras*) *serpentinum*, *Cœloceras Desplacei*, *C. Holandrei* (15-30 feet); 2, marls with *Lioceras complanatum*, *Hildoceras bifrons*, *Turbo capitaneus* (26 feet); 3, marls with *Turbo subduplicatus*, *Cœloceras crassum* (12-20 feet); 4, blue marls with *Cancellophycus liassicus* (25-30 feet). Near St. Amand, Cher, the stage consists of nearly 200 feet of marls and clays with seven recognisable zones. In the Haute Marne, it is nearly as thick. In the Rhone basin it consists of a lower group of limestones with *Pecten æquivalvis*, and an upper group of ferruginous beds, including an important seam of oolitic ironstone, and containing the zones of *Hildoceras bifrons* and *Lioceras* (*Harpoceras*) *opalinum*. In Provence, it consists of a thick mass of dark shales with some limestones below and above, the whole reaching a thickness of 950 feet. In Normandy, the Toarcian stage is only 20 feet thick, but shows the characteristic ammonite zones.

3. Charmouthian.[1]—The stage thus named corresponds to the English Middle Lias and the upper part of the Lower Lias, or zones 8 to 13 of the table on p. 1133. In Lorraine, where it reaches a thickness of 230 to 260 feet, it consists of the following three assises in ascending order:—1, limestones (*Deroceras* (*Ægoceras*) *Davæi*) and marls with phosphates; 2, marls and ferruginous concretions (*Amaltheus margaritatus*); 3, sandstones (*Gryphæa regularis*). In the French Ardennes, it is 360 feet thick, and comprises: 1, sandy clay with *Microderoceras* (*Ægoceras*) *planicostatum*, *Gryphæa regularis*, *Plicatula spinosa*; 2, marl with *Belemnites clavatus*, *Ægoceras capricornu*; 3, ferruginous limestone with *Paltopleuroceras* (*Amaltheus*) *spinatum*, *Bel. paxillosus*. Westwards this stage becomes almost wholly marly. In Yonne and Côte d'Or, it is divisible into three assises, in the following ascending order: 1, Belemnite limestone of Venarey (40 feet), comprising the zones of (*a*) *Cycloceras* (*Ægoceras*) *Valdani*, (*b*) *Ægoceras venarense*, (*c*) *Liparoceras Henleyi*, (*d*) *Deroceras* (*Ægoceras*) *Davœi*; 2, micaceous and pyritous marls, about 200 feet; 3, nodular limestone with large gryphites, and *Pecten æquivalvis*. In western Switzerland and the adjoining tracts of France M. Haug has shown that three facies of the Liassic series can be observed, arranged in three parallel bands round the crystalline core of the Cottian Alps. The first, that of the Briançonnais, presents a series of crystalline, often brecciated, limestones, sometimes coraliferous, and abounding in lamellibranchs and gasteropods, with but a trifling intercalation of shales and marls. The second or Dauphinian consists of marly or compact, never crystalline, limestones and clays, with abundant cephalopods, but no gryphæas, brachipods, or gasteropods, and sometimes reaching the great thickness of more than 6000 feet. The third or Provençal is composed chiefly of bedded limestones about 2000 feet thick, with abundant crinoids, brachipods, and lamellibranchs.[2]

2. Sinemurian.[3]—This stage corresponds to the greater part of the Lower Lias of England, comprising all this formation from the base of the *Armatus* zone down to the top of the *Angulatus* zone. As its name denotes, it is typically developed around Semur in the Côte-d'Or, where it consists of nodular gryphite limestone with marly bands (23-26 feet), and is divisible into three zones, which, counting from below, are marked respectively by: 1, *Arietites* (*Coroniceras*) *rotiformis*; 2, *A.* (*Coroniceras*) *Bucklandi*; 3, *A.* (*Asteroceras*) *stellaris*, *A. obtusus*, and *Waldheimia cor*. Near St. Amand, Cher, it is composed of about 15 feet of marly limestone, which represent only its upper part. In the Haute Marne and Jura, it is a limestone with curved gryphites, and ranges from 15 to 25 feet in thickness. In the basin of the Rhone it is a calcareous formation, 20 to 25 feet thick, containing in ascending order the zones of *Arietites Davidsoni*, *A. stellaris*, *Oxynoticeras oxynotum*, *Microderoceras* (*Ægoceras*) *planicostatum*. Farther south, it swells out in Provence to 275 feet, and is separable into a lower group with *Arietites* (*Coroniceras*) *Bucklandi*, and a higher with *Belemnites acutus* and *Arietites bisulcatus*. In Normandy, it is about 100 feet thick, and comprises clays and marly gryphite limestones (*A. bisulcatus*), surmounted by gryphite limestones and clays (*Belemnites brevis*, *Waldheimia cor.*).

[1] From Charmouth, in Dorset, where the stage is well developed.

[2] M. Haug, *Bull. Carte Géol. France*, No. 21 (1891); Lory, *B. S. G. F.* (3) ix.

[3] Named by D'Orbigny from Semur in the Côte-d'Or where the stage is well displayed.

1. Hettangian,[1] corresponding to the *Angulatus* and *Planorbis* zones at the base of the English Lias, rests conformably on the sandstones, marls, and bone-bed of the *Avicula contorta* zone or Rhætic group. In the Hettange district the zone of *Psiloceras planorbe*, composed of dark bituminous marls and fetid limestones (10 to 40 feet), contains *Cardinia Deshayesi*, and is succeeded by the sandstone of Hettange (nearly 200 feet), with *Schlotheimia angulata* and numerous other fossils, among which are abundant shells of *Cardinia*, with *Plicatula*, *Pecten*, *Lima*, *Montlivaltia*, and a number of ferns and cycads (*Thaumatopteris*, *Dictyophyllum*, *Thinnfeldia*, *Cycadites*, *Otozamites*). The zone becomes less sandy as it advances into Belgium, where it forms the Marne de Jamoigne. The Hettangian stage of Burgundy is thin, and is composed of a lower Lumachelle de Bourgogne (*Ostrea irregularis*, *Cardinia Listeri*, *C. sinemurensis*, *C. trapezium*, *C. hybrida*, *Oxynoticeras Burgundiæ*) and an upper marly limestone known as "Foie de Veau" (*Arietites liasicus*, *Schlotheimia angulata*, *S. moreana*, *Oxynoticeras Burgundiæ*, *Littorina clathrata*, *Cardinia*, &c.). In the basin of the Rhone, the *Planorbis* zone is about 40 feet thick, and the *Angulatus* zone 20 to 26 feet. In Cotentin, the stage is divisible into a lower sub-group of marls (*Mytilus minutus*, *Corbula Ludovicæ*) and an upper sub-group of limestones (*Cardinia concinna*, *Pecten valoniensis*).

One of the most interesting features of the Lias in the northern or Jura part of Switzerland is the insect-beds at Schambelen in the Canton Aargau. The insects are better preserved and more varied than those in the English Lias. They include representatives of Orthoptera, Neuroptera, Coleoptera (upwards of 100 species of beetles), Hymenoptera, and Hemiptera. About half of the beetles are wood-eating kinds, so that there must have been abundant woodlands on the Swiss dry land in Liassic time.[2]

Germany.—In north-western Germany the subjoined classification of the Jurassic system has been adopted:[3]—

Upper or White Jura[3] (Malm.)		Purbeck group (Serpulit, a limestone 160 feet thick, and Münder Mergel, a series of red and green marls, with dolomite and gypsum, at least 1000 feet thick), forming a transition between the Purbeck and Portland groups.
		Eimbeckhäuser Plattenkalke and zone of *Olcostephanus gigas*, equivalent to the English Portland group (*Corbula*, *Modiola*, *Viviparus*, *Cyrena*).
		Kimeridge group, Upper, with *Exogyra virgula* = Virgulian; Middle or *Pterocera* (*Harpagodes*) beds (Pterocerian); Lower (Astartian, Upper Sequanian), with *Nerinæa* beds and zone of *Terebratula humeralis*.[4]
		Corallian, with *Cidaris florigemma*, corals, *Pecten varians*, *Ostrea rastellaris*, *Nerinæa visurgis*.
		Oxfordian, with *Gryphæa dilatata*, *Aspidoceras perarmatum*, *Cardioceras cordatum*.
		Clays with *Cosmoceras ornatum*, *C. Jason*, *Quenstedtoceras Lamberti*, *Reineckia anceps*, *Peltoceras athleta* = "Ornatus clays." This stage is usually included by German geologists in the Middle Jura.
	Upper 20–100 ft.	Clays, shales, and ferruginous oolite with at the top the zone of *Macrocephalites macrocephalus*, equivalent to the Callovian or Kellaways rock, and at the bottom that of *Parkinsonia Parkinsoni*.
		"Bifurcatus-schichten" with *Parkinsonia* (*Cosmoceras*) *bifurcata*. These "Bifurcatus beds," with the Hauptrogenstein

[1] Named by Professor Renevier from the sandstone of Hettange in Luxemburg. This stage has been widely known as that of the "Infra-Lias."

[2] Heer, 'Urwelt der Schweiz,' p. 82.

[3] Heinr. Credner, *Ober. Jura in N. W. Deutschland*, 1863. See also the works of Oppel and Quenstedt quoted on p. 1132, and K. von Seebach's *Der Hannoversche Jura*, 1864. Brauns' *Unter. Mittl. und Ober. Jura*, 1869, 1871, 1874. O. Fraas, 'Geognostische Beschreibung von Württemberg, Baden und Hohenzollern,' Stuttgart, 1882. Th. Engel, 'Geognostischer Wegweiser durch Württemberg, Stuttgart (1883).

[4] Struckmann, *N. Jahrb.* 1881 (ii.), p. 102.

Middle or Brown Jura (Dogger).	Middle 50 ft.	above them, including the zones of *Oppelia fusca* and *O. aspidoides*, form the Bathonian stage.[1]
		"Coronatus-schichten," clays with *Stephaoceras humphriesianum*, and many corals of the genera *Montlivaltia*, *Thecosmilia*, *Cladophyllia*, *Isastraea*, *Confusastraea*, *and Thamnastraea*.[2]
		Ostrea limestone with *Ostrea Marshi*, *O. eduliformis*, *Trigonia costata*.
		Clays with *Belemnites giganteus*.
	Lower	Shales, sandstones, and ironstones, with *Inoceramus polyplocus*, *Ludwigia (Harpoceras) Murchisonæ*, *Pecten personatus*.
		Clays and shales with *Lioceras (Harpoceras) opalinum*, *Trigonia navis*.
Lower or Black Jura (Lias).	Upper 30 ft.	Grey marls with *Lytoceras jurense* (Jurensis-Mergel), *Grammoceras (Harpoceras) radians*.
		Bituminous shales (Posidonien-Schiefer) with *Harpoceras lythense*, *Dactylioceras (Cœloceras) commune*, *Harpoceras bifrons*, *Posidonomya Bronni*.
	Middle 80-100 ft.	Clays with *Paltopleuroceras (Amaltheus) spinatum*, *Amaltheus margaritatus*, *Belemnites paxillosus*.
		Marls and limestones with *Ægoceras capricornu*, *Deroceras Davœi*.
		Dark clays and ferruginous marls with *Phylloceras ibex*, *Uptonia (Ægoceras) Jamesoni*, *Terebratula numismalis*.
	Lower 100-115 ft.[3]	Clays with *Arietites obtusus (Turneri)*, *Oxynoticeras oxynotum* (Oxynotenlager).
		Oil shales and Pentacrinus beds resting on gryphite limestone with *Arietites Bucklandi*, *Gryphæa arcuata*, *Lima gigantea*, *Spiriferina Walcotti* (Arietenschichten).
		Sandstones with *Schlotheimia angulata* (Angulatenschichten), *Cardinia Listeri*.
		Dark clays, sandy layers, and limestone with *Psiloceras planorbe* (*psilonotum*) (Psilonotenkalk).

In lithological characters the German Lower or Black Jura presents many points of resemblance to the English Lias. Some of the shales in the upper division are so bituminous as to be workable for mineral oil. With the general succession of organisms also, so well worked out by Oppel, Quenstedt, and others, the English Lias has been found to agree closely.

The Dogger or Brown Jura represents the Lower Oolite of England and the Étages Bajocien and Bathonien of France. Its lower division consists mainly of dark clays and shales, passing up in Swabia into brown and yellow sandstones with oolitic ironstone.[4] The central group in northern Germany differs from the corresponding beds in England, France, and southern Germany by the great preponderance of dark clays and ironstone nodules. The upper group consists essentially of clays and shales with bands of oolitic ironstone, thus presenting a great difference to the massive calcareous formation on the same platform in England and France.

The Malm, or Upper or White Jura corresponds to the Middle and Upper Oolites of England, from the base of the Oxford clay upwards, with the equivalent formations in France. It is upwards of 1000 feet thick, and derives its name from the white or light

[1] For an account of the fauna of this stage in the upper Rhenish lowland see A. O. Schlippe, *Abhand. Geol. Specialkart. Elsass-Lothr.* IV. Heft iv. (1888).

[2] G. Meyer, "Korallen des Doggers," *Abhand. Geol. Specialkart. Elsass-Lothr.* IV. Heft v. (1888).

[3] For an account of this stage see J. A. Stuber, *Abhandl. Geol. Specialkart. Elsass-Lothr.* V. ii. (1893).

[4] For a detailed stratigraphical and palaeontological account of the Lower Dogger of German Lorraine see W. Branco, *Abhand. Geol. Specialkart. Elsass-Lothr.* II. Heft ii. (1879).

colour of its rocks contrasted with the dark tints of the Jurassic strata below. It consists mainly of white limestones in many varieties; other materials are dolomite and calcareous marl. Its lower (Oxfordian) group is essentially calcareous, but with some of the fossils which occur in the Oxford clay, *e.g. Cosmoceras ornatum* and *Gryphæa dilatata*. The massive limestones with *Cidaris florigemma* are the equivalents of the Corallian. The Kimeridge group presents at its base beds equivalent to part of the Sequanian or Astartian sub-stage of France (*Astarte supracorallina*, *Natica globosa*, &c.), with such an abundance and variety of the gasteropod genus *Nerinæa* that the beds have been named the "Nerineen-Schichten." Above these come strata with *Harpagodes* (*Pterocera*) *Oceani* (Pterocerian), marking the central zone of the Kimeridgian stage. Higher still lie compact and oolitic limestones with *Exogyra virgula* (Virgulian). At the top some limestones and marly clays yield *Olcostephanus gigas* (Portlandian). The most important member of the German Kimeridgian stage is undoubtedly the limestone long quarried for lithographic stone at Solenhofen, near Munich. Its excessive fineness of grain has enabled it to preserve in the most marvellous perfection the remains of a remarkably varied and abundant fauna both of the sea and land. Besides skeletons of fishes (*Aspidorhynchus*, *Lepidotus*, *Megalurus*), cephalopods showing casts of their soft parts, crabs with every part of the integument in place, and other denizens of the water, there lie the relics of a terrestrial fauna washed or blown into the neighbouring shallow lagoons—dragon-flies with the lace-work of their wings, and other insects; the entire skeletons of Pterodactyle and Rhamphorhynchus, in one case with the wing membrane preserved (Figs. 435-437), and the remains of the earliest known bird, *Archæopteryx* (Fig. 438). The upper Jurassic series is well developed in Hanover, where it has been carefully studied by C. Struckmann. The Portland group was shown by him to contain eighty-five species of fossils, one-half of which are lamellibranchs, and to include the characteristic ammonites *A. gigas*, *portlandicus*, *Gravesianus*, *giganteus*.[1] The German Purbeck group attains an enormous development in Westphalia (1650 feet), where, between limestones full of *Corbula*, *Viviparus*, and *Cyclas*, pointing to fresh-water deposition, there occur beds of gypsum and rock-salt.

Alps.—The Jurassic system in the Alps is developed under a different aspect from its varied characters in central and western Europe. It there includes massive reddish limestones or marbles like those of the Trias of the same region. Indeed it would seem that the pelagic conditions under which the Triassic limestones were deposited had not entirely passed away when the Jurassic formations came to be laid down. We have seen (*ante*, p. 1152) that in the western part of the Alpine chain three distinct types of the Lias are to be found. In the Tyrol and eastern Alps the Lias presents still other lithological and palæontological characters. A distinguishing feature is the prominence of red and variegated marbles, also the abundance of genera of ammonites which are for the most part feebly represented in central and western Europe. Of those familiar in the latter regions, some of the conspicuous forms are species of *Phylloceras*, *Lytoceras*, *Amaltheus*, *Oxynoticeras*, *Arietites*, *Psiloceras*, and *Schlotheimia*. At Adneth, in Salzburg, this facies has been long studied. In the Hierlatz Mountains of the Salzkammergut the Lias is represented by massive white and pink limestones with abundant brachiopods. Yet with these calcareous deposits there are also developed along the southern borders of Bohemia and eastwards in Hungary, sandy and argillaceous strata containing so much vegetation as to afford in some places beds of coal.[2] The Alpine Lias, in spite of these variations of character and organic contents, shows here and there some of the distinctive ammonite zones, so that it can be placed in comparison with that of the rest of Europe. It lies conformably on and passes down into the Rhætic series.

The equivalents of the English Lower Oolites or "Middle Jura" of the Continent

[1] 'Der Obere Jura der Umgegend von Hanover,' 1878; *Palaeontolog. Abhand.* (Dames u. Kayzer) I. i. (1882); *Zeitsch. Deutsch. Geol. Ges.* 1887 p. 32.

[2] Neumayr, *Abhand. k. k. Geol. Reichsanst.* 1879.

have been detected in both the western and eastern Alps, but are not well developed there. In the west, where they are about 1300 feet thick, they consist of limestones, shales, and clays with calcareous nodules, which form regular alternations. Ammonites, especially of the genera *Phylloceras* and *Lytoceras*, abound, together with *Posidonomya*. The zones of *Ludwigia* (*Harpoceras*) *Murchisonæ*, *Lioceras* (*Harpoceras*) *concavum*, *Sonninia Sowerbyi*, *S. Romani*, *Stephoceras humphriesianum*, *Parkinsonia Parkinsoni* and *Oppelia fuscus* have been recognised.[1]

The Oxfordian and Corallian divisions of the Jurassic system, or Callovian, Oxfordian, and Sequanian formations, are in general feebly represented in the Alpine region; but the Upper Oolites or Kimeridgian and Portlandian series attain a large development. It is this higher part of the system which in the Alps specially presents the Tithonian facies already referred to. Above the zone of *Oppelia tenuilobatum* (*Aspidoceras acanthicum*) comes a mass of strata consisting of a lower group of reddish well-bedded limestones so full of *Terebratula diphya* (*Pygope janitor*) as to be named the "Diphya-limestone"; and of an upper thick-bedded or massive light-coloured limestone (Stramberg limestone, from Stramberg in Moravia). The limestones are often crowded with cephalopods, of which a large number of species, many of them peculiar, have been noticed (*Phylloceras ptychoicum*, *Simoceras volanense*, *Sonninia* (*Waagenia*) *hybonota*, *Perisphinctes transitorius*, *Oppelia lithographica*, *O. steraspis*). The presence of some of these shells in the Portlandian rocks of Germany serves to place all these Alpine limestones at the very top of the Jurassic system. About a dozen species of fossils pass up from them into the Cretaceous rocks. The shales or impure shaly limestones are sometimes full of the curious cephalopod opercula known as *Aptychus* (Aptychus-beds). Some of the more massive limestones are true coral-reefs. Many of the limestone escarpments of the Alps (Hochgebirgskalk) are referable to the *Terebratula diphya* beds. In some places they are overlain by the "Diphyoides-beds" (with *Terebratula* [*Pygope*] *diphyoides*), elsewhere they pass insensibly upwards into the so-called *Biancone*—a white compact siliceous limestone containing Cretaceous cephalopods. The Diphya-limestone, with its peculiar fossils, appears to range from the Carpathians through the Alps and Apennines (where it occurs as a marble) into Sicily.[2]

Mediterranean Basin.—The older members of the Jurassic system have been more or less distinctly recognised by the evidence of fossils over a wide region around the Mediterranean. The Lias appears in various parts of the Spanish peninsula, generally in a dolomitised condition. In the centre of the Apennine chain, where the plications of that region have brought it to the surface, it is found in the form of limestones with ammonites and variegated marls (*Arietites*, *Schlotheimia*, *Lytoceras*, &c.). In Calabria the Lower Lias has been estimated to consist of upwards of 1500 feet of white crystalline limestones (*Spiriferina*, *Waldheimia*). The formation crosses into Sicily, where it has yielded some of its typical fossils. On the eastern side of the Adriatic it rises again in Bosnia, and has been found in Epirus, and in the opposite island of Corfu.[3]

Middle and Upper Jurassic formations have a similar distribution. They have been recognised in Spain and Portugal from the Lias to the Portlandian, the Tithonian

[1] Haug, *Bull. Cart. Géol. France*, No. 21 (1891).

[2] In the voluminous literature of this subject the following works may be consulted: Oppel, *Z. Deutsch. Geol. Ges.* xvii. (1865), 535. Neumayr, *Abhandl. Geol. Reichsanstalt*, v. Zittel, *Paläont. Mittheil. Mus. Bayer.* Hébert, *Bull. Soc. Géol. France*, ii. (2) p. 148, xi. (3) p. 400. E. W. Benecke, 'Trias und Jura in den Südalpen,' 1866. 'Geognostisch. Paläontologische Beiträge,' 8vo, Munich, 1868. C. Moesch, 'Jura in den Alpen, Ostschweiz,' 1872. E. Fraas, 'Scenerie der Alpen.' See also the 'Jura-studien,' &c., of Neumayr, already cited (p. 1129), and the papers of Favre, Loriol, Renevier, and others.

[3] G. Stache, *Abhand. Geol. Reichsanst.* Vienna, xiii. (1889). A. Philippson and G. Steinmann, *Z. D. G. G.* xlvi. (1894), p. 116. Partsch, *Petermann. Mitth.* (Ergänzungsheft, No. 88, 1887).

facies becoming strongly marked in the higher formations (p. 1148). While these strata are generally of marine origin, their higher members in Portugal present increasing evidence of terrestrial conditions, until in what may be the equivalent of the Sequanian and Kimeridgian stages an abundant flora has been preserved, embracing 126 species (71 ferns, 7 cycads, 26 conifers, 8 monocotyledons), among which perhaps the most interesting forms are some that are regarded as primitive types of angiosperms. A remarkable similarity has been traced between this assemblage of plants and that found in the American Trias, three species and fourteen genera being common to both, while on the other hand a still more striking resemblance has been traced between it and that obtained from the Lower Cretaceous formations of the United States. We shall find that in some parts of Portugal a gradual passage can be traced from Jurassic into Cretaceous strata, and that the terrestrial conditions of that region continued into Cretaceous time, their record being preserved in a higher group of strata wherein another abundant flora has been entombed.[1] The Jurassic formations reappear in the Balearic Isles, Sardinia, and Sicily, while in Italy the Tithonian type of the highest members comes out strongly among the great marble series of the chain of the Apennines. Jurassic fossils have likewise been obtained from the eastern part of the Mediterranean basin. Those collected at Mount Hermon in Palestine indicate an Oxfordian horizon. The system is thus prolonged from the European region into Asia.

Russia.—Jurassic formations spread over a larger area in Russia than in any other part of Europe, for they sweep northwards over a vast breadth of territory to the White Sea, and extend eastwards into Asia. Yet in this wide area it is mainly the upper half of the system which appears. The Lias and other formations of the Lower Jurassic series have been traced in the south of the empire. Some of them are found in the Crimea, whence they are prolonged on either side of the Caucasian chain, but chiefly on the north side as far as the plains of the Caspian Sea. Over the northern half of the country the various formations from the Callovian up into the Cretaceous system have been identified. The fauna of these Russian Jurassic formations, however, is so peculiar, and for a long time yielded so few species found elsewhere in Europe, that it was difficult to correlate the rocks with those of better known regions. More sedulous research has now in large measure removed this difficulty, by showing that some of the recognised life-zones of western Europe can be detected in Russia.[2] At the bottom lies (1) the Callovian stage, consisting of clays, divided into—*a.* Lower with *Kepplerites* (*Cosmoceras*) *calloviense*, *Cosmoceras gowerianum*; *b.* Middle with *Cosmoceras Jason*, *Stepheoceras coronatum*; *c.* Upper with *Quenstedtoceras Lamberti*, *Cosmoceras Duncani*. (2) Oxfordian, composed of dark sandy clays and divided into—*a.* Lower with *Cardioceras cordatum*, *C. vertebrale*, *Perisphinctes plicatilis*, *Aspidoceras perarmatum*; *b.* Upper with *Cardioceras alternans*, *Perisphinctes Martelli*. (3) Volgian (of Prof. Nikitin), consisting of green, brown, and dark sandstones and clays, which extend up to the shores of the Arctic Sea. They contain *Perisphinctes Bleicheri*, *P. Nikitini* with species of *Hoplites*, *Virgatites*, and a great abundance of the lamellibranch genus *Aucella*. This group is correlated by Pavlow with the Portlandian stage of western Europe. This author arranges the several Upper Jurassic groups in the Syzran district as follows:—1. Kimeridgian, marly clays with *Reineckia* (*Hoplites*) *pseudomutabilis*; 2. Portlandian or Bononian, consisting of (*a*) *Bleicheri*-beds, shales, and clays with *Belemnites magnificus*, *Aucella Pallasi*, and crushed ammonites of the *Bleicheri* type, (*b*) *Virgatus*-beds—phosphatic conglomerate and shales with *Virgatites virgatus*, *Belemnites absolutus*, &c.,

[1] P. Choffat, "Receuil de Monographies Stratigraphiques," *Serv. Geol. Portugal*, 1885-1900. De Saporta, *Compt. rend.* cxi. p. 812. L. F. Ward, 16*th Ann. Rep. U.S. G. S.* (1896), p. 520, and *postea*, p. 1206.

[2] Neumayr, *Geogn. Palaeontol. Beiträge*, 1876, vol. ii. Nikitin, *Neues Jahrb.* 1886, ii. p. 205; *Mém. Acad. St. Pétersbourg*, 1881. Pavlow, *Bull. Soc. Géol. France*, xii. (1884); *Bull. Soc. Nat. Moscou*, 1889, 1891.

(c) *Giganteus*-beds—glauconitic sandstone, with large ammonites of the *Giganteus* type: 3. Aquilonian, consisting of calcareous sandstone and comprising (1) a lower sub-stage or zone of *Ammonites fragilis, subditus*, and *catenulatus*, (2) a middle zone of *A. nodiger* and *A. subclypeiformis*, and (3) an upper zone of *Hoplites riasensis*. All these zones are so connected with each other by the presence of the same *Belemnites* and *Aucellæ* (*A. Fischeri*, &c.), as to form a natural group which is regarded by Prof. Pavlow as the marine equivalent of the Purbeck beds. It is further linked with the Lower Neocomian by forms having Neocomian affinities. There is thus a marked similarity in these respects between it and the Speeton series of the Yorkshire coast.[1]

Sweden.—The coal-bearing Rhætic series developed in Scania and referred to on p. 1098 is followed by a series of marine strata, in which a number of the ammonite-zones of the Lower and Middle Lias have been recognised as high as that of *Amaltheus margaritatus*.[2] At Höganäs the lowest strata, comprising the Planorbis and Angulatus zones, consist of the following bands, which still show a mingling of terrestrial traces. At the base lie beds with *Cardinia Follini, Guthieria angustiloba, Sagenopteris rhoifolia*. These are overlain with a layer containing *Cyclas Nathorsti* and insect remains. Then comes a bank of oysters (*O. Hisingeri, Gervillia scanica*), followed by one full of Aviculas (*A. inequivalvis*) with *Tancredia securiformis* and *T. arenacea*. The uppermost member of the series here represents the *Bucklandi*-zone, and contains a number of ammonites (*A. sauzeanus, A. scipionianus, A. Bucklandi, A. bisulcatus*) with *Ostrea arcuata, Avicula inequivalvis, Pecten janiformis*, &c. At Kurremölla the Middle Lias is represented by strata containing *Uptonia Jamesoni* and other fossils. Jurassic formations appear also on the island of Bornholm. On the island of Andö, at the north end of the Lofoden group, Jurassic deposits have long been recognised. They include traces of a terrestrial vegetation (*Baiera, Scleropteridium, Phœnicopsis. Pinus*, &c.),[3] together with marine shells (*Gryphæa dilatata, Lima duplicata, Pecten validus, P. nummularis, Aucella Keyserlingi*, and some undetermined ammonites and belemnites), which perhaps indicate Oxfordian or higher horizons.[4]

Arctic Regions.—The Triassic series in Spitzbergen already referred to is followed by Jurassic strata, which appear to belong to the lower or middle part of the system. They have yielded *Lytoceras tripartitum* and a *Cadoceras*. From the neighbouring King Charles Islands Professor Nathorst has made known the existence of representatives of the Brown Jura. The Tertiary basalts have there overflowed and preserved a series of Cretaceous and Jurassic strata. In the latter the Bathonian stage is believed to be represented by beds containing *Pseudomonotis echinata*, and the Kellaways group by overlying deposits in the lower part of which *Macrocephalites Ishmæ*, var. *arctica*, is found, while higher up *Cadoceras* and *Belemnites subextensus* occur.[5]

The presence of a Lower Oxfordian or Callovian stage in the east of Greenland, within ten degrees of the pole, has been proved by the discovery of *Macrocephalites macrocephalus, Cadoceras Tchefkini?, C. modiolaris, Belemnites Panderi*, &c. Below this stage lies another band containing *Macrocephalites Ishmæ* and three species of belemnites, which may perhaps represent the Cornbrash. In the same group of strata a characteristically Jurassic flora is met with, including species of *Phyllotheca, Anomozamites, Zamiopteris, Asplenium*, &c.[6] Farther south on the Greenland coast,

[1] Pavlow, *Bull. Soc. Nat. Moscou*, 1891; *Q. J. G. S.* lii. (1896), p. 542. See further on this subject a paper by Prof. E. Haug, "Portlandien, Tithonique et Volgien," *B. S. G. F.* xxvi. (1898), p. 197.

[2] B. Lundgren, *Universit. Aarskrift.*, Lund, xxiv., 1888. J. C. Moberg, *Sverig. Geo. Undersökn.*, Stockholm, 1888.

[3] Heer, 'Flora Fossilis Arctica,' iv. 3 (1877).

[4] B. Lundgren, *Videnskabs-Selsk. Förhandl.*, Christiania, 1894, No. 5.

[5] *Geol. Fören. Förhandl.*, Stockholm, xxiii. (1901), p. 341.

[6] Messrs. Newton and Teall, *Q. J. G. S.* liii. (1897), p. 477; liv. (1898), p. 646.

Jurassic rocks have been found at Cape Stewart on Scoresby Sound (lat. 70°·25), where thirty-seven species have been described, probably indicating a Callovian horizon.[1]

America.—So far as yet known, rocks of unquestionably Jurassic age play but a subordinate part in North American geology. No marine Jurassic rocks have yet been found along the Atlantic border. Some geologists have regarded the upper part of the estuarine Newark series (p. 1110) as rather Jurassic than Triassic. With more palæontological force the late Professor Marsh strongly maintained that the Potomac formation, which has generally been placed in the Cretaceous system, should be regarded as the equivalent and representative of the lacustrine Atlantosaurus beds of the interior of the continent, which, on the ground of their vertebrate fauna, have been admitted to be Jurassic. As has been recently shown, the so-called Potomac formation is probably Jurassic in its lower and Cretaceous in its upper portion.[2]

In the centre of the continent marine fossils of Lower Jurassic age have been obtained in Wyoming, Dakota, and other states. Above this marine platform comes a series of highly-coloured clays of lacustrine origin, full of vertebrate remains, to which further reference will be made in the next paragraph. In California a representative of the European Lias has been found containing ammonites of the *Arietites* type. Middle Jurassic rocks appear to exist in the same State, where the upper part of the system is also well represented. Lower Jurassic formations extend into Oregon, and reappear among some of the islands within the Arctic Circle (Grinnell, Prince Patrick, Bathurst). Remains of *Ichthyosaurus* were brought by Sir E. Belcher from Exmouth Island. Jurassic strata not only stretch along the western slopes of North America, but also along those of the southern half of the same vast continent. From Bolivia and Argentina representatives of the Lower and Middle formations have been announced.[3]

The clays above the marine platform above referred to have been studied by Professor Marsh, who obtained a large series of vertebrate remains from them in Wyoming and Colorado. He subdivided them into two groups: (*a*) the *Baptanodon*-beds at the base, so named from the genus of large swimming reptiles entombed in them; (*b*) the *Atlantosaurus*-beds, of which that gigantic deinosaur is especially characteristic. The discovery of so remarkable a fauna gave a wholly new interest and importance to the Jurassic rocks of America. Among remains of fish (*Ceratodus*), tortoises, pterodactyles, and crocodilians, there occur the bones of herbivorous deinosaurs (*Atlantosaurus*, *Brontosaurus*, *Stegosaurus*, *Morosaurus*, *Apatosaurus*), together with the carnivorous *Creosaurus* and the curious ostrich-like *Laosaurus*. With this rich and striking reptilian fauna are associated the remains of many genera of small mammals named by Marsh *Allodon*, *Ctenacodon*, *Dryolestes*, *Stylacodon*, *Asthenodon*, *Laodon*, *Diplocynodon*, *Docodon* [*Enneodon*], *Menacodon*, *Tinodon*, *Triconodon*, *Priacodon*, *Paurodon*.[4]

Asia.—From Asia Minor and the basin of the Caspian the Jurassic formations are prolonged eastwards through Kurdistan and Persia to Afghanistan and India, reappearing even in Borneo and Japan. In Afghanistan the Triassic series referred to on p. 1107 is overlain with plant-bearing sandstones and volcanic bands which at their base contain marine fossils that have been referred to this geological system. Of the great

On the Jurassic fauna of Cape Flora, Franz Joseph Land, see J. F. Pompecky in Nansen's 'Norwegian North Polar Expedition,' 1893-96, p. 147, and on the flora, Nathorst in same volume, p. 26.

[1] B. Lundgren, 'Meddelelser om Grönland,' xix. (1895).

[2] Marsh, *Amer. Journ. Sci.* ii. (1896), p. 433: vi. (1898) p. 105. See *postea*, p. 1210.

[3] Steinmann, *Neues Jahrb.*, 1884, p. 199. O. Behrenden, *Z. D. G. G.* xliii. (1891), p. 309. The latter writer reports Lower and Middle Lias and higher Jurassic beds from the eastern slopes of the Argentine Cordilleras.

[4] Marsh, *Amer. Journ. Sci.* xv. (1878) p. 459; xviii. (1879) pp. 60, 215, 396; xx. (1880) p. 235; xxi. (1881) p. 511; xxxiii (1887), p. 237; *Geol. Mag.* (1887) pp. 241, 289. The fresh-water invertebrates are described by C. A. White, *B. U.S. G. S.* No. 29 (1886).

Gondwana system of India the upper members have been likewise paralleled with the Jurassic rocks of Europe. Unconformably above the Panchet group (p. 1107) come the Rajmahal dolerites and basalts of Bengal, with associated grey and carbonaceous shales, sandstones, and grits, reaching a thickness of at least 2000 feet, of which the sedimentary intercalations never exceed 100 feet in the aggregate. These strata have furnished a large number of terrestrial plants (ferns, cycads, and conifers), which are strongly marked off from those in the Lower Gondwana formations, being especially distinguished by the great predominance of cycads, particularly of *Ptilophyllum acutifolium.* Higher in the series are the Golapilli beds, which besides land-plants contain marine shells (*Stepheoceras opis, Macrocephalites, Perna, Gervillia, Nuculana, Trigonia*). Near Madras also, in the Upper Gondwana series, besides the land-plants, there occur ill-preserved ammonites and other shells. It is in Cutch, however, that marine Jurassic formations are best developed. In that district lies a series of strata, estimated to be 6300 feet thick, of which the lower half consists of limestones, oolites, shales, and sandstones of marine origin, while the upper half is mostly sandstone, shale, and conglomerate, with land-plants. This series has been subdivided into the following groups in ascending order: (1) Patcham (=Bathonian), consisting of (*a*) lower yellow sandstones and limestones with Trigoniæ (*T. costata*), Corbulæ, &c.; (*b*) light grey limestones and shales with *Œcotraustes serrigerus.* (2) Chari (=Callovian and part of Oxfordian), composed of four groups, viz.: (*c*) shales and calcareous bands with *Macrocephalites macrocephalus, M. tumidus, Sphæroceras bullatum, Oppelia subcostata, Perisphinctes funatus*; (*d*) shales with *Perisphinctes obtusicosta*; (*e*) white limestones with *Peltoceras athleta, Oppelia bicostata*; (*f*) oolites with *Stepheoceras Polyphemus, Perisphinctes indo-germanus, Peltoceras arduennense*, &c. (3) Katrol (=part of Oxfordian and Kimeridgian): (*g*) red ferruginous and yellow sandstones with *Stepheoceras maya, Aspidoceras perarmatum, Perisphinctes virguloides*; (*h*) sandstones and shales with *Phylloceras ptychoicum, Neumayria trachynota, Perisphinctes torquates.* (4) Umia (=Portland and Tithonian of southern Europe, and passing up into representatives of the Neocomian formations). Only the lower part of this group need here be quoted. It consists of (*i*) sandstones and conglomerates with *Perisphinctes Bleicheri, P. suprajurensis, P. frequens, P. denseplicatus, Trigonia Smeei, T. ventricosa.* The last two fossils have likewise been recognised in strata overlying the Rajmahal group, and thus supply a link to connect the Upper Gondwana rocks with the Jurassic series of Cutch. Altogether 177 species of cephalopods have been obtained from these Cutch deposits, of which at least 50 are common to the Jurassic formations of Europe. It is noticeable also that the European ammonite zones are repeated with remarkable similarity in this Indian region.[1]

Jurassic rocks are found in the west half of the Salt Range, but their sequence and palæontological relations have not been worked out. In the Himalaya chain the fossils of the Spiti shales have long been known, inasmuch as they had acquired a sacred character and become objects of commerce.[2] They indicate the presence in that region of Callovian and Kimeridgian horizons. The Spiti shales have been recognised to the north of the Karakoram range in one direction, and in Hazara on the other. Jurassic rocks have likewise been reported from the north of Nepal. The Jurassic system has been recognised in small detached areas of Japan, and presents there both a marine and brackish-water type. The marine strata appear to represent the lower part of the system or Lias, for they include species of *Harpoceras, Perisphinctes, Arietites,* and *Ægoceras*, some of which are allied to, if not identical with, European forms, together with *Trigonia costata* and species of *Cyrena, Gervillia, Perna*, &c. The land-plants (chiefly ferns and cycads) number about fifty species, nineteen of which are also found

[1] 'Manual of the Geology of India,' 2nd edit. chaps. vii., viii., and ix.

[2] On the Jurassic formations of the Himalayas and Central Asia, see S. Nikitin *Neues Jahrb.*, 1889, ii. p. 116.

in the European Lower Jurassic series, such as *Thyrsopsis murrayana*, *Dicksonia nephrocarpa*, *Asplenium whitbyense*, *Pecopteris exilis*, *Nilssonia orientalis*, *Podozamites lanceolatus*, *Ginkgo digitata*, *Pinus Nordenskjoldi*.[1]

Africa.—Jurassic rocks have been recognised in widely separated parts of this continent. The Lias appears in Algeria, where some of its lower beds contain *Cardinia* and *Spiriferina Walcotti*, while its higher members are better developed and have yielded *Grammoceras radians*, *G. toarcense*, *Pylloceras heterophyllum*, and other forms.[2]

Bathonian formations have been noted in Abyssinia, in Somaliland, and much farther south in Cape Colony. They cross over into the west side of Madagascar.

Australasia.—The existence of Jurassic rocks in Queensland and western Australia has been demonstrated by the discovery of recognisable Jurassic species and others closely allied to known Jurassic forms.[3] In Queensland above the Permo-Carboniferous rocks comes the Burrum formation, a great series of coal-bearing rocks, with *Sphenopteris*, *Thinnfeldia*, *Alethopteris*, *Tæniopteris*, *Podozamites*, *Otozamites*, *Baiera*, and a few animal remains, including species of *Corbicula* and *Gastrochænia* (*Rocellaria*). This group is followed by another sandy and conglomeratic series with abundant remains of land-plants and workable coals, forming the valuable Ipswich formation. From these strata a large flora has been collected, together with cyprids, coleoptera, and *Unio*. From the plant-remains these two formations have been grouped as Jura-Trias.[4] Traces of Jurassic rocks have been found in New Caledonia and the northern end of New Guinea.

In New Zealand a thick series of rocks classed as Jurassic is subdivided by Sir J. Hector as follows:—

Mataura series, estuarine, with terrestrial plants (8 species known).

Putakaka series, marlstones and sandstones passing into conglomerates, and enclosing plant-remains and irregular seams of coal; marine fossils (11 species known) of Middle Oolite facies.

Flag Hill series, with species of *Rhynchonella*, *Terebratula*, *Spiriferina*, &c.

Catlin's River and Bastion series, consisting in the upper part of conglomerates and grits, with obscure plant-remains, and in the lower part of sandstones. Fossils abundant (especially ammonites), and affording means for defining horizons. This division is referred to the Lias.[5]

A somewhat different classification has been published by Captain Hutton, who comprises these strata in his "Hokanui system," which he estimates to be in the southern part of Otago between 20,000 and 25,000 feet thick, and which he subdivides into two sections, the lower termed the "Wairoa series," regarded by him as Triassic, and the "Mataura series" above, paralleled by him with the Jurassic formations of other countries. Terrestrial plants are found all through the system, and in the upper part thin seams of coal often occur, the most characteristic plants being species of *Pterophyllum*, *Podozamites*, *Thinnfeldia*, *Tæniopteris*, and *Polypodium*. The Wairoa series yields *Monotis salinaria*, *Halobia Lomelli*, *Mytilus problematicus*, and *Spirigera Wreyi*, &c.; while the Mataura series is characterised by *Ammonites novo-zelandicus*, *Belemnites aucklandicus*, *B. Hochstetteri*, *B. catlinensis*, *Inoceramus Haasti*, *Aucella plicata*.[6]

Section iii. Cretaceous.

The next great series of geological formations received the name of Cretaceous from the fact that, in north-western Europe, one of its most

[1] 'Outlines of the Geology of Japan,' by Imp. Geol. Surv., Tokyo, 1900, p. 52.

[2] Ficheur, *B. S. G. F.* (3) xxiv. p. 1142.

[3] Moore, *Q. J. G. S.* xxvi. 261. W. B. Clarke, *op. cit.* xxiii. 7. R. Etheridge, jun., 'Catalogue of Australian Fossils,' 1878.

[4] Jack and Etheridge, 'Geology and Palæontology of Queensland' (1892), chaps. xxiii.-xxx.

[5] Hector's 'Handbook of New Zealand,' p. 31.

[6] *Q. J. G. S.*, 1885, p. 202; *Trans. New Zealand Inst.* xxxii. (1899) p. 165.

important members is a thick band of white chalk (*creta*). It presents very considerable lithological and palæontological differences as it is traced over the world. In particular, the white chalk is almost wholly confined to the Anglo-Parisian basin where the system was first studied. Probably no contemporaneous group of rocks presents more remarkable local differences than the Cretaceous system of Europe. These differences are the records of an increasing diversity of geographical conditions in the history of the Continent.

§ 1. General Characters.

Rocks.[1]—In the European area, as will be afterwards pointed out in more detail, two tolerably distinct areas of deposit can be recognised, each with its own character of sedimentary accumulations, as in the case of the Jurassic system already described. The northern tract includes Britain, the lowlands of central Europe southwards into Silesia, Bohemia, and round the Ardennes into the basin of the Seine. The southern region embraces the centre and south of France, the range of the Alps, and the basin of the Mediterranean eastwards into Asia. In the northern area, which appears to have been a basin in great measure shut off from free communication with the Atlantic, the deposits are largely of a littoral or shallow-water kind. The basement beds, usually sands or sandstones, sometimes conglomerates, are to a marked extent glauconitic (greensand). The marked diffusion of glauconite, both in the sandstones and marls, is one of the distinctive characters of this series of rocks. Another feature is the abundance of soluble silica (sponge-spicules), more particularly in the formation called the Upper Greensand, and in the Lower Chalk of many parts of the south and south-east of England and the north of France. In Saxony and Bohemia, the Cretaceous system consists chiefly of massive sandstones, which appear to have accumulated in a gulf along the southern margin of the northern basin. Considerable bands of clay, occurring on different platforms among the European Cretaceous rocks, are often charged with fossils, sometimes so well preserved that the pearly nacre of the shells remains, in other cases encrusted or replaced by marcasite. Alternations of soft sands, clays, and shales, usually more or less glauconitic, are of frequent occurrence in the lower parts of the system (Neocomian and older Cenomanian). The calcareous strata assume sometimes the form of soft marls, which pass into glauconitic clays, on the one hand, and into white chalk on the other. The white chalk itself is a pulverulent limestone, mainly composed of fragmentary shells and foraminifera.[2] Its upper part shows layers

[1] The most detailed information regarding the mineralogical and chemical composition of the rocks of this system will be found in Cayeux's monograph cited on p. 106. See also an essay by Dr. W. F. Hume, "Chemical and Micro-mineralogical Researches on the Upper Cretaceous Zones of the South of England," London, 1893.

[2] For a comparison of chalk with modern *globigerina*-ooze, see Cayeux, as above cited, p. 490.

of flints, which are irregular lumps of dark-coloured, somewhat impure chalcedony, disposed for the most part along the planes of bedding, but sometimes in strings and veins across them. The flints frequently enclose silicified fossils, especially sponges, urchins, brachiopods, &c.[1] (see pp. 179, 625, 831). The chalk, in some places, becomes a hard dull limestone, breaking with a splintery fracture. Nodular phosphate of lime or phosphatic chalk, occurring on different horizons in the system, is extensively worked as a source of artificial manure in the Upper Chalk of Belgium.[2] It has been found also in the north of France, and at Taplow, near Maidenhead, in England.[3]. The chalk of Britain and the north of France not infrequently contains pebbles and even boulders of granite, quartzite, sandstone, coal, or other foreign rocks. Various explanations have been proposed to account for these transported materials. On the whole, it seems most probable that, as in the case of the boulders in the Coal-measures (p. 1016), they were originally entangled among the roots of trees which, being swept down by floods, floated out to sea and dropped their freight of soil and stones to the bottom.[4]

The terrestrial vegetation of the period has in different places been aggregated into beds of coal. These occur in north-western Germany among the Wealden deposits, where they are mined for use; also to a trifling extent in the Wealden series of England; they are likewise found in the Cenomanian series of Saxony and the Senonian of Magdeburg. The upper Cretaceous (Laramie) rocks of the Western Territories of the United States consist largely of sandstones and conglomerates, among which are numerous important seams of coal. Beds of concretionary brown iron-ore are present in the Cretaceous series of Hanover, and similar deposits were once worked in the English Wealden series. In the southern European basin, where the conditions of deposit appear to have been more those of an open sea freely communicating with the Atlantic, the most noticeable feature is the massiveness, compactness, and persistence of the limestones over a vast area. These rocks, often crowded with hippuritids, from their extent and organic contents, indicate that, during Cretaceous times, the Atlantic stretched across the south of Europe and north of Africa, far into the heart of Asia, and may not impossibly have been connected across the north of India with the Indian Ocean.

LIFE.—The Cretaceous system, both in Europe and North America, presents successive platforms on which the land-vegetation of the period has been preserved, though most of the strata contain only marine organisms. This terrestrial flora possesses a great interest,

[1] See W. J. Sollas, *Ann. Mag. Nat. Hist.* vi. (1880), p. 437.

[2] Cornet, *Q. J. G. S.* xlii. p. 325. Renard et Cornet, *Bull. Acad. Roy. Belg.* xxi. (1891) p. 126. For a recent contribution on this subject, see J. Gosselet, *Ann. Soc. Géol. Nord.* xxx. (1901) p. 208.

[3] A. Strahan, *Q. J. G. S.* xlvii. (1891) p. 356.

[4] For the literature of this subject see M. Cayeux's work above cited, p. 418.

for it includes the earliest known progenitors of the abundant dicotyledonous angiosperms of the present day. In Europe during the earlier part of the Cretaceous period, it appears to have closely resembled the vegetation of the previous ages, for the same genera of ferns, cycads, and conifers, which formed the Jurassic woodlands, are found in the rocks. Yet that angiosperms must have already existed is made certain by the sudden appearance of numerous forms of that class, at the base of the Upper Cretaceous formations in Saxony and Bohemia, whence forms of *Acer*, *Alnus*, *Credneria*, *Salix*, and other dicotyledons have been obtained. Similar evidence of the appearance

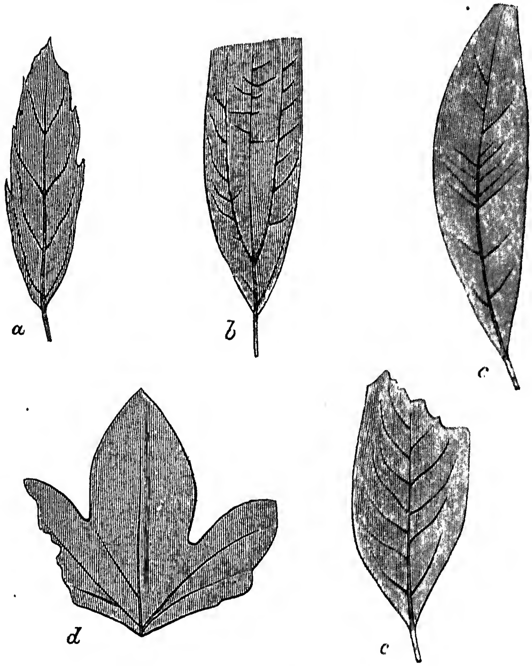


Fig. 446.—Cretaceous Plants.
a, Quercus rinkiana (2/3); *b*, Cinnamomum sezannense (2/3); *c*, Ficus atavina (1/3); *d*, Sassafras recurvata (2/3); *e*, Juglans arctica (1/2).

of *Quercus*, *Sassafras*, *Platanus*, and many other dicotyledons, in the midst of abundant ferns and cycads, has been obtained from the Lower Cretaceous series of the Spanish peninsula and the United States. Still more varied and abundant is the flora preserved in the Upper Cretaceous formations in Westphalia, from which many species of dicotyledonous plants have been obtained, belonging to the genera *Populus*, *Myrica*, *Quercus*, *Ficus*, *Credneria*, *Viburnum*, *Eucalyptus*, &c., besides algæ, ferns, cycads, conifers, and various monocotyledons (Fig. 446).[1] Another rich Cretaceous

[1] Hosius and Von der Marck, "Die Flora der Westfälischen Kreideformation,"

flora, found in the corresponding beds at Aix-la-Chapelle, includes numerous ferns (*Gleichenia*, *Lygodium*, *Danæites*, *Asplenium*, *Pteridoleimma*), conifers (*Sequoia*, *Cunninghamites*), angiosperms, *Caulinites*, *Dryophyllum*, *Myricophyllum*, *Ficus*, *Laurophyllum*, and three or four kinds of screw-pine (*Pandanus*).[1] The prevalent forms which give so modern an aspect to this flora, and which occur also in Westphalia, have been regarded by some botanists as Proteaceæ, and have even been referred to genera still living in Australia or at the Cape of Good Hope. The climate of Europe, at the close of the Cretaceous period, was doubtless greatly warmer than that which now prevails, and nourished a vegetation like that of some parts of Australia or the Cape. Further information has been afforded regarding the extension of this flora by the discovery in North Greenland of a remarkable series of fossil-plants, of which Heer described nearly 200 species, including more than 40 kinds of ferns, with club-mosses, horsetail reeds, cycads (*Cycas*, *Podozamites*, *Otozamites*, *Zamites*), ginkgoaceæ (*Ginkgo*, *Baiera*), conifers (*Juniperus*, *Thuyites*, *Sequoia*, *Dammara*, *Pinus*, &c.), monocotyledons (*Arundo*, *Potamogeton*, &c.), and many dicotyledons, including forms of poplar, myrica, oak, fig, walnut, plane, sassafras, laurel, cinnamon, ivy, aralia, dogwood, magnolia, eucalyptus, ilex, buckthorn, cassia, and others.[2]

In North America, also, abundant remains of a similar vegetation have been obtained from the Potomac formation and the Cretaceous rocks of the West. The Laramie group of strata in particular has yielded a remarkably large and varied flora. Out of more than 100 species of dicotyledonous angiosperms there found, half are related to still living American trees. Among them are species of oak, willow, beech, plane, poplar, maple, hickory, fig, tulip-tree, sassafras, laurel, cinnamon, buckthorn, together with ferns, American palms (sabal, *Flabellaria*), conifers, and cycads.[3] The Potomac formation of Virginia and Maryland has a special interest from its age. It is referred with some probability to the Neocomian period, and it had, up to the year 1895, yielded about 198 genera and 737 species of plants. These included 31 genera of ferns, 14 of cycads, 34 of conifers, and 8 of monocotyledons. But besides this assemblage, which is distinctly Mesozoic in character, the deposits have furnished no fewer than 92 genera and 330 species of dicotyledons. Of these higher forms of vegetation the more peculiar seem to be what are known as "generalised types," indicating the great antiquity of the flora. But among the genera there are found *Aralia*, *Cinnamomum*, *Ficus*, *Hedera*, *Ilex*, *Juglans*, *Juniperus*, *Laurus*, *Magnolia* (5 species), *Myrica*, *Platanus*, *Quercus*, *Rhamnus*, *Salix*, *Sassafras*, *Viburnum*.[4]

Palæontographica, xxvi. (1880) p. 125. The total flora described by these observers is made up of 85 species from the Upper and 20 species from the Lower Cretaceous beds.

[1] Debey and Ettingshausen, *Denksch. Akad. Wien.* xvi. (1859), xvii. (1860). T. Lang, *Z. D. G. G.* 1890, p. 658. H. von Dechen, as cited *postea*, p. 1204.

[2] 'Flora Fossilis Arctica,' vols. vi. and vii. (1882-83).

[3] For a synopsis of the Laramie flora see L. F. Ward, *6th Ann. Rep. U.S. G. S.* 1885; see also Newberry, *Monograph* xxxv. *U.S. G. S.* (1898).

[4] W. M. Fontaine, 'The Potomac or Younger Mesozoic Flora,' *Monog.* xv. *U.S. G. S.*

The known Cretaceous fauna is tolerably extensive. Foraminifera now reached an importance as rock-builders which they had never before

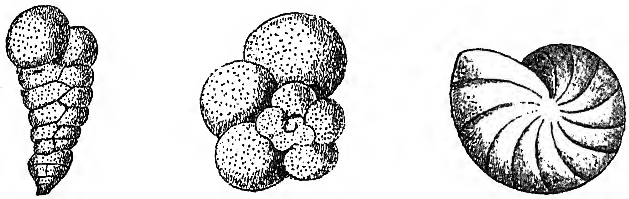


Fig. 447.—Cretaceous Foraminifera.
a, Gaudryina pupoides, D'Orb.; *b*, Globigerina cretacea, D'Orb.; *c*, Cristellaria rotulata, D'Orb. (all magnified).

attained. Their remains are abundant in the white chalk of the northern European basin, and some of the hard limestones of the southern basin are mainly composed of their aggregated shells. The glauconite grains of many of the greenish strata are the internal casts of foraminiferous shells (see pp. 181, 627). Some of the more frequent genera are *Alveolina*, *Ammodiscus*, *Bulimina*, *Calcarina*, *Cristellaria*, *Discorbina*, *Globigerina*, *Lagena*, *Marginulina*, *Orbitolina*, *Polymorphina*, *Rotalia*, and *Textularia* (Fig. 447).[1] Radiolaria have been found abundantly in some parts of the system, but their skeletons appear to be liable to alteration when entombed in a silt of mixed siliceous and calcareous composition, which may account for their disappearance from strata in which they might have been expected to occur.[2] Representatives of the Liosphærids, Astrosphærids, Staurosphærids, Discoids, Cyrtoids, and Stephoids have been detected in the English Cretaceous series.[3] Calcareous Sponges are of frequent occurrence, as in the genera *Peronidella*, *Corynella*, *Barroisia*, while siliceous forms must have swarmed on the floor of the Cretaceous seas, for their siliceous spicules are abundant, entire individuals are not uncommon, and they appear to have mainly contributed to the formation

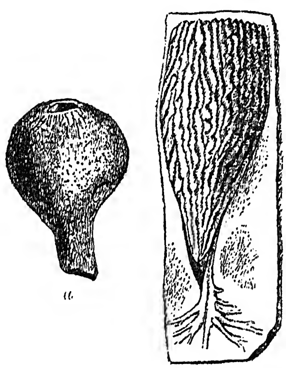


Fig. 448.—Cretaceous Sponges.
a, Siphonia tulipa, Zitt. (½); *b*, Ventriculites decurrens, var. tenuiplicatus, Smith (½).

(1889); L. F. Ward, *15th Ann. Rep. U.S. G. S.* (1895), pp. 386-393. See also O. Feistmantel, *Z. D. G. G.* 1888, p. 27.

[1] For a catalogue of Cretaceous foraminifera see T. Rupert Jones, *Geol. Mag.* 1900, p. 225; also F. Chapman, *Q. J. G. S.* l. (1894), p. 726. The foraminifera of the Aix-la-Chapelle Chalk are described by J. Beissel, *Abhandl. Preuss. Geol. Landesanst.* Neue Folg. Heft 3.

[2] W. Hill and A. J. Jukes-Browne, *Q. J. G. S.* li. (1895) p. 600.

[3] Mr. W. M. Holmes has described 20 genera and 41 species from the Upper Chalk of Coulsdon, Surrey, *Q. J. G. S.* lvi. (1900) p. 694. See also the work of M. Cayeux.

of the important accumulations of flint and chert.[1] Characteristic siliceous genera (Fig. 448) are *Siphonia*, *Cœloptychium*, *Coscinopora*, *Ventriculites*, *Cephalites*, and *Plocoscyphia* and *Stauronema*. Undoubtedly sponges, as well as radiolaria, secreted an enormous quantity of silica from the water of the Cretaceous sea, and though the flints are certainly not due merely to the direct action of these organisms alone, amorphous silica may have been aggregated by a process of chemical elimination round dead sponges or other organisms (p. 625). Mollusks and urchins have been completely silicified in the Chalk.

On the whole, Corals are not abundant in Cretaceous deposits. They seem to have been chiefly solitary forms, though in the Maestricht beds of Denmark, the Faxoe coral-limestone, the Neocomian and

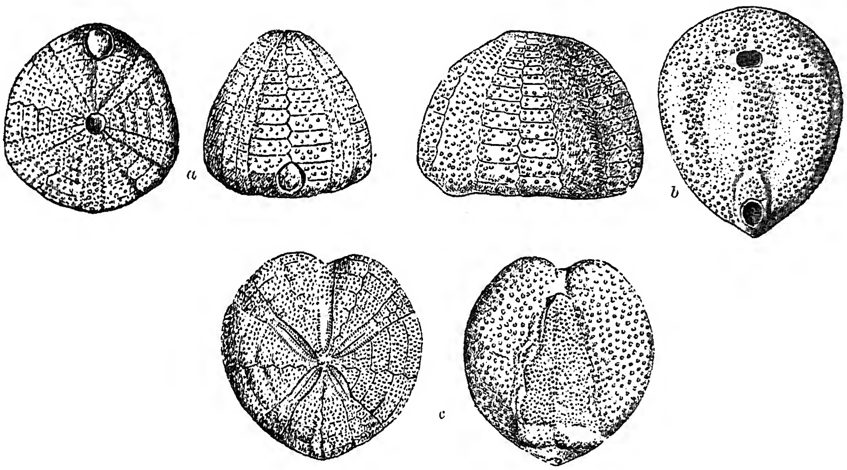


Fig. 449.—Upper Cretaceous Echinoids.
a, Galerites (Echinoconus) conicus, Brey. (=Galerites albo-galerus, Lam.) (2/3); *b*, Ananchytes ovatus (=Echinocorys vulgatus, Leske) (1/2); *c*, Micraster cor-anguinum, Klein (1/2).

Turonian series of France, the Turonian rocks of the Alps and Pyrenees, true reefs have been met with, and the corals of Gosau are well known. Some of the more characteristic genera are *Trochocyathus*, *Caryophyllia*, *Trochosmilia*, *Parasmilia*, *Microbacia*, *Cyclolites*, and *Holocystis*. Sea-urchins are conspicuous among the fossils of the Cretaceous system. A few of their genera are also Jurassic, while a not inconsiderable number still live in the present ocean. One of the most striking results of modern deep-sea dredging is the discovery of so many genera of echinoids, either identical with, or very nearly resembling, those of the

[1] See on Sponge spicules, papers by Professor Sollas, *Ann. Mag. Nat. Hist.* ser. 5, vi. and memoirs by Dr. G. J. Hinde, 'Fossil Sponge Spicules,' Munich, 1880; 'Cat. of Fossil Sponges, British Museum,' 1883; *Phil. Trans.* vol. clxxvi. p. 403, 1886; 'British Fossil Sponges,' *Pal. Soc.* vol. xl. xli. 1887-88. The sponge spicules of the Upper Cretaceous rocks are very generally in the condition of amorphous or colloid silica; those of the Lower Cretaceous are frequently of crystalline silica.

Cretaceous period, and having thus an unexpectedly antique character.[1] Some of the most abundant and typical Cretaceous genera (Fig. 449) are *Cidaris*, *Orthocidaris*, *Salenia*, *Hemicidaris*, *Pseudodiadema*, *Cyphosoma*, *Echinocyphus*, *Conoclypeus*, *Echinocyamus*, *Galerites* (*Echinoconus*), *Anorthopygus*, *Collyrites*, *Ananchytes* (*Echinocorys*), *Echinospatagus* (*Toxaster*), *Holaster*, *Micraster*, *Hemiaster*, *Hemipneustes*, *Cardiaster*, *Pygurus*, *Echinobrissus* (*Nucleolites*), *Discoidea*, *Phymosoma* (*Cyphosoma*). The Crinoids continue to be represented in the Cretaceous system, of which *Marsupites*, *Uintacrinus*, *Phyllocrinus*, and *Bourgueticrinus* are characteristic. Star-fishes are common on some horizons, particularly species of *Calliderma*, *Pentagonaster*, and other genera.[2]

Polyzoa abound in some parts of the system, especially in the upper formations, from which D'Orbigny described no fewer than 850 species.

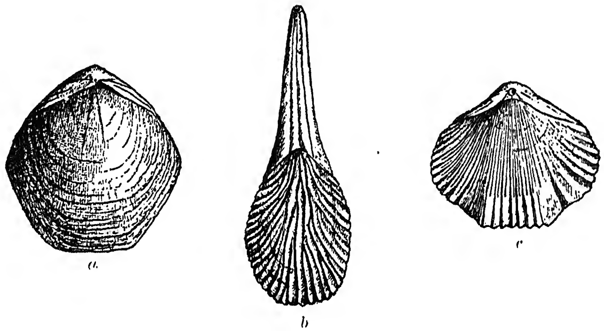


Fig. 450.—Cretaceous Brachiopods.
a, Terebratula carnea, Sow. (⅔) ; *b*, Lyra (Terebrirostra) lyra, Sow. (⅔) ; *c*, Rhynchonella plicatilis, var. octoplicata, Sow. (⅔).

Some of the more frequent genera are *Cellaria*, *Onychocella*, *Membranipora*, *Micropora*, *Stomatopora*, *Proboscina*, *Berenicea*, *Crisina*, and *Entalophora*.[3] The Brachiopods (Fig. 450) are abundantly represented by Rhynchonellids and Terebratulids, characteristic types being species of *Rhynchonella*, *Peregrinella*, *Terebratula*, *Magas*, *Terebratulina*, *Terebratella*, *Kingena*, *Lyra* (*Terebrirostra*), *Trigonosemus* (*Fissirostra*), besides representatives of the ancient Lingulids, Discinacea, Craniacea, and Thecidiidæ.

Among the most abundant genera of Lamellibranchs[4] (Fig. 454) are

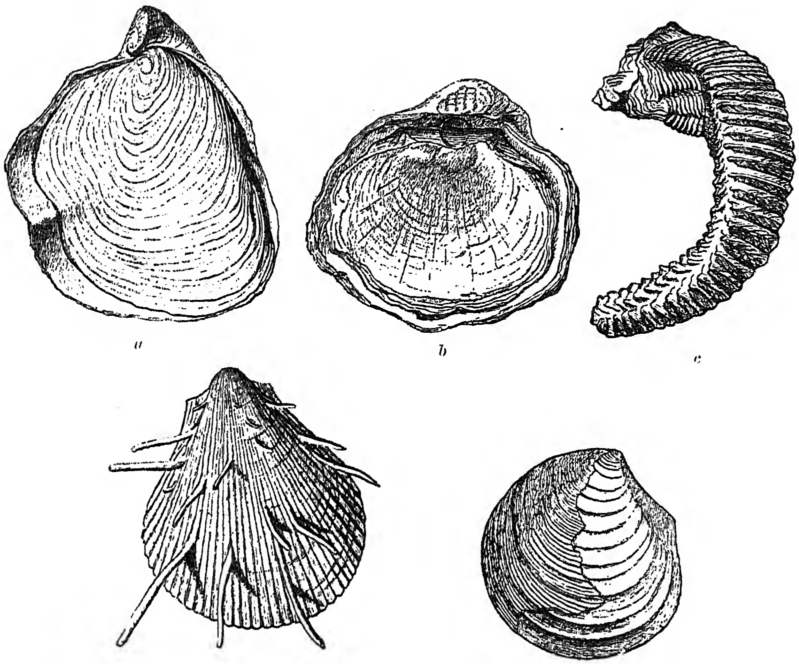
[1] A. Agassiz, "Report on Echinoidea," *Challenger* Expedition, vol. iii. p. 25. Dr. A. W. Rowe has shown the great value of the genus *Micraster* for purposes of zonal arrangement in the Chalk, *Q. J. G. S.* lv. (1899) p. 494.

[2] The regular echinids of the Chalk as found in North Germany are described by C. Schlüter, *Abhandl. Preuss. Geol. Landesanst.* Neue Folg. Heft 5. The Cretaceous Asteroidea are described by W. P. Sladen in the volumes of the Palæontograph. Soc. 1891-1893.

[3] See J. W. Gregory, 'Catalogue of Fossil Bryozoa in the British Museum : The Cretaceous Bryozoa,' 1899.

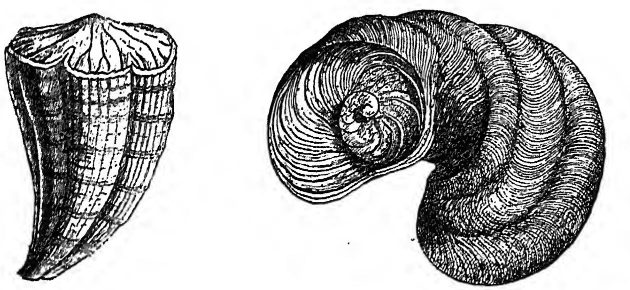
[4] An important contribution to this part of the palæontology of the system is the monograph by Mr. H. Woods, 'The Cretaceous Lamellibranchs of England,' *Palæontograph. Soc.*

Inoceramus, *Gervillia*, *Aucella*, *Exogyra*, *Chlamys*, *Ostrea*, *Spondylus*, *Lima*,



a b c d e

Fig. 451.—Cretaceous Lamellibranchs.
a, Exogyra columba, Lam. (½); *b*, Ostrea vesicularis, Lam. (½); *c*, Ostrea (Alectryonia) carinata, Lam. (½); *d*, Spondylus spinosus, Desh. (⅔); *e*, Inoceramus Cuvieri, Sow. (young spec.) (½).



a b

Fig. 452.—Cretaceous Lamellibranchs.
a, Hippurites (Batolites) organisans, Desm. (nat. size); *b*, Requienia ammonia, D'Orb. (¼).

Plicatula, *Pecten*, *Perna*, *Modiola*, *Trigonia*, *Isocardia*, *Cardium*, *Venus*, and

1899-1902. The bivalves and gasteropods of the German and Dutch Neocomian rocks are described in Heft 31, Neue Folge, of the *Abhandl. Preuss. Geol. Landesanst.*

Exogyra are specially characteristic, but still more so are the families of Monopleurids, Caprinids, Radiolitids, and Hippuritids. These singular forms are entirely confined to the Cretaceous system: their most common genera (Fig. 452) being *Monopleura*, *Caprina*, *Caprinula*, *Caprotina*, *Radiolites*, *Sphærulites*, and *Hippurites*, to which may be added the diceratid genus *Requienia* so characteristic of the Lower Cretaceous formations of

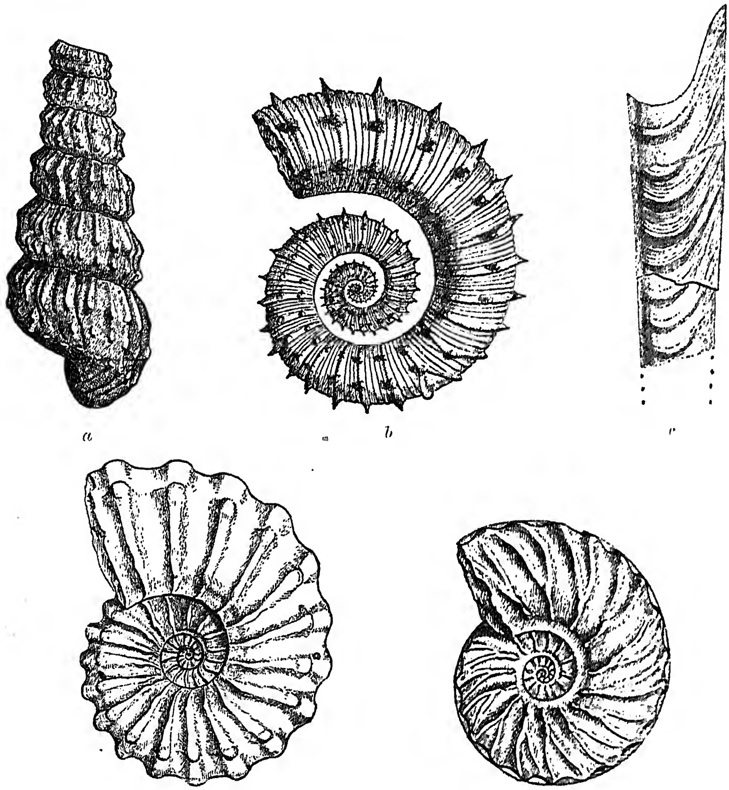


Fig. 453.—Cretaceous Cephalopods.
a, Turrilites costatus, Lam. (½); *b*, Crioceras Emerici, Lév. (½); *c*, Baculites anceps, Lam. (½); *d*, Acanthoceras rothomagense, Brong. (¼); *e*, Schlœnbachia varians, Sow. (⅔).

Southern Europe.[1] Hence, according to present knowledge, the occurrence of these families in a limestone suffices to indicate the Cretaceous age of the rock. The Gasteropods are represented by the genera *Pleurotomaria*, *Emarginula*, *Solarium*, *Turbo*, *Trochus*, *Dejanira*, *Natica*, *Glauconia*, *Cerithium*, *Aporrhais*, *Strombus*, *Pseudoliva*, *Fusus*, *Fasciolaria*, *Volutilithes*, *Oliva*, *Pleurotoma*, *Conus*, *Actæonella*, *Avellana*, and many more.

[1] For a study of the *Rudistes*, see the Memoir by H. Douvillé, *Mém. Soc. Géol. France* (3), i. (1890); ii. (1892).

Cephalopods (Figs. 453-455) are abundant in the Anglo-Parisian basin and thence eastwards, but are comparatively infrequent in the south European Cretaceous area. To the geologist, they have a value similar to those of the Jurassic system, as distinct species are believed to be restricted in their range to particular horizons, which have by their means

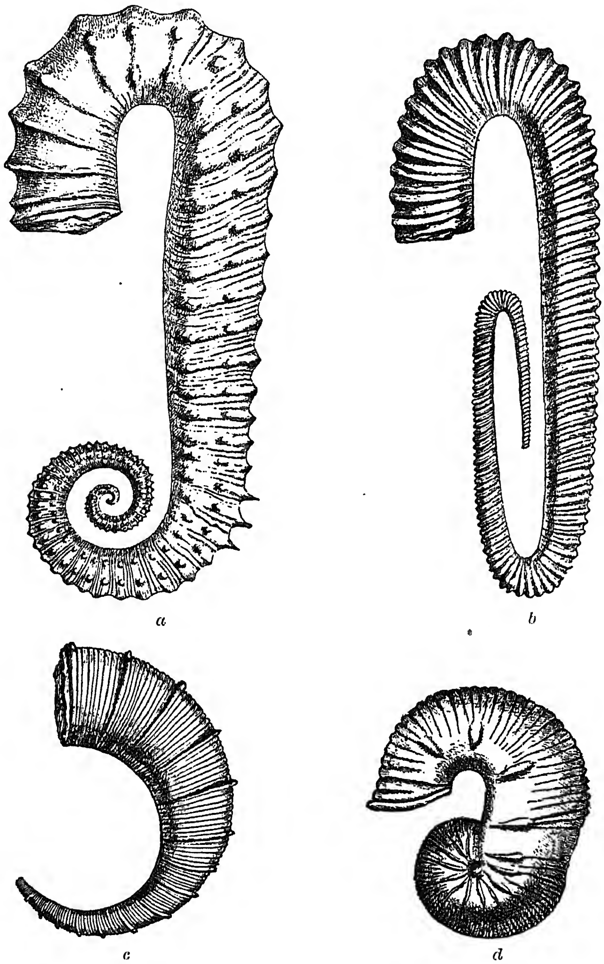


Fig. 454.—Cretaceous Cephalopods.
a, Ancyloceras matheronianum, D'Orb. (1/8); *b*, Hamites attenuatus, Sow. (1/2); *c*, Hamites bituberculatus, D'Orb.; *d*, Scaphites æqualis, Sow.

been identified from district to district. To the student of the history of life, they have a special interest, as they include the last of the great Mesozoic tribes of the Ammonites and Belemnites. These organisms continue abundant up to the top of the Cretaceous system, and then

disappear from the European geological record.[1] Cephalopodous life, though manifestly on the decline, was still displayed in many varied types in the Cretaceous seas. It included some old Ammonite genera such as *Phylloceras* and *Haploceras*, some of which had continued from older Jurassic time. A remarkable feature in the Cretaceous types is the number of uncoiled or irregularly coiled forms which now make their appearance. These singular shapes are regarded by some naturalists as evidences of degeneration, due perhaps to some widespread geographical conditions unfavourable to the further advance of ammonoid development, by other writers as indications of the senility of the race. They are not made the basis of classification, which is now founded mainly on the peculiarities of the sutures and saddles. The same family may thus include ordinary coiled and uncoiled or even straight forms, and the same

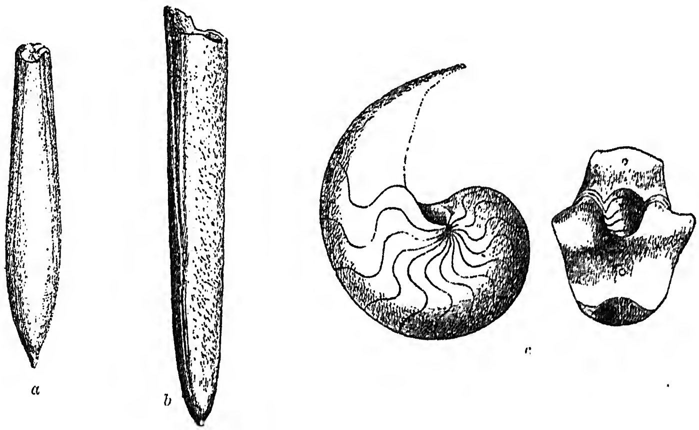


Fig. 455.—Upper Cretaceous Cephalopods.
a, Actinocamax plenus (formerly Belemnitella plena), Blainv. (⅓); *b*, Belemnitella mucronata. Schloth. (½); *c*, Nautilus danicus, Schloth. (½).

shell may be a normal ammonite in its earlier life and more or less completely uncoiled in its later stages. Some of these curious aberrations from the normal ammonoid type are represented in Figs. 453 and 454. Characteristic and peculiar Cretaceous Tetrabranchiates are *Tetragonites*, *Scaphites*, *Ptychoceras*, *Macroscaphites*, *Baculites*, *Hoplites*, *Sphenodiscus*, *Placenticeras*, *Douvilleiceras*, *Acanthoceras*, *Hamites*, *Anisoceras*, *Turrilites*, *Ancyloceras*, *Crioceras*, *Mammites*, *Peroniceras*, *Prionotropis*, *Schlœnbachia*,

[1] No abrupt disappearance of a whole widely-diffused fauna probably ever took place. The cessation of Ammonites with the Cretaceous system in Europe can only mean that in this area there intervened between the deposition of the Cretaceous and Tertiary strata a long interval, marked by such physical revolutions as to extirpate Ammonites from that region. That the tribe continued elsewhere to live on into Tertiary time appears to be proved by the occurrence of some Ammonite remains in the oldest Tertiary beds of California. A. Heilprin, 'Contributions to the Tertiary Geology and Palæontology of the United States,' Philadelphia, 1884, p. 102.

Tissotia. The dibranchiate Cephalopods are represented by species of *Belemnites*, *Belemnitella*, *Actinocamax* (Upper Cretaceous), *Belemnoteuthis*, and *Actinosepia*.

Vertebrate remains have been obtained in some number from the Cretaceous rocks. Fish are represented by scattered teeth, scales, or bones, sometimes by more entire skeletons. Among the Elasmobranch genera are *Ptychodus*, *Hybodus*, *Acrodus*, *Lamna*, *Oxyrhina*, and *Hemipristis*. The ganoids include *Macropoma*, *Pholidurus*, *Gyrodus*, *Lepidotus*, *Amiopsis*, and others. But the most notable aspect of the fish fauna of the Cretaceous seas was the marked predominance of forms that possessed a completely ossified internal skeleton. These types, the ancestors of the ordinary teleostean tribes of the present day, began their existence in the Liassic period, perhaps even earlier. The most important primitive families among them were the Elopidæ (*Elopopsis*, *Osmeroides*, *Pachyrhizodus*) and the Ichthyodectidæ, represented by the genera *Ichthyodectes*, *Portheus*, *Cladocyclus*, *Saurodon*, and others. Among the modern families which can

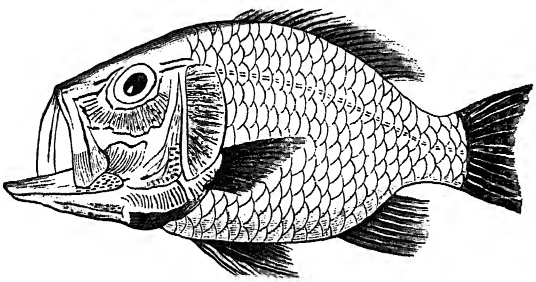


Fig. 456.—Cretaceous Fish.
Hoplopteryx lewesiensis (½).

be traced back into the Cretaceous period are those of the herrings or Clupeidæ (*Diplomystus*), the eels or Muraenidæ (*Urenchelys*), the sea-breams or Sparidæ, and the Berycidæ, which appear in a number of genera (*Sphenocephalus*, *Acrogaster*, *Pycnosterinx*, *Hoplopteryx*, Fig. 456, *Homonotus*). Other types are *Platycormus*, *Berycopsis*, *Aipichthys*, *Cimolichthys*, *Enchodus*.[1]

Reptilian life has not been so abundantly preserved in the Cretaceous as in the Jurassic system, nor are the forms so varied. In the European area the remains of Chelonians of several genera (*Chelone*, *Rhinochelys*) have been recovered. The last of the tribe of deinosaurs died out towards the close of the Cretaceous period. Among the Cretaceous forms of this order are the *Megalosaurus* and *Ornithopsis*, which survived from Jurassic time; other genera are *Acanthopholis*, *Hylæosaurus*, *Hypsilophodon*, *Polacanthus*, *Titanosaurus*, *Vectisaurus*. *Iguanodon* is the most familiar type among them (Fig. 457), some of its teeth and bones having been first found many years ago in the Wealden series of Sussex, while in

[1] A. S. Woodward's 'Catalogue of Fossil Fishes' (British Museum), Part IV. 1901.

recent years, almost entire skeletons have been disinterred from the ancient alluvium filling up ravines or valleys of the Cretaceous period in Belgium.

Fig. 457.—Cretaceous Deinosaur (Iguanodon). From the skeleton as restored and erected by MM. de Paw and Dollo in the Brussels Museum.

Its osteology is accordingly now well known. Like other deinosaurs, it had many affinities with birds. Palæontologists have differed in opinion as to whether it walked on all fours or erect. M. Dollo, who has had

the advantage of working out the structure of the wonderfully perfect Belgian specimens, believes that the animal moved on its hind legs, which are disproportionately longer than the fore ones. Its powerful tail obviously served as an organ of propulsion in the water, and likewise to balance the creature as it walked. Its strange fore-limbs, armed with spurs on the digits, doubtless enabled it to defend itself from its carnivorous congeners; it was itself herbivorous.[1] Among Cretaceous rocks the order of Squamata (lizards) is represented by *Coniosaurus*, *Dolichosaurus*, and *Leiodon*. The gigantic *Mosasaurus*, placed among lacertilians by Owen, but among "pythonomorphs" by Cope, is estimated to have had a length of 75 feet, and was furnished with fin-like paddles, by which it moved through the water. True crocodiles frequented the rivers of the period, for the remains of several genera have been recognised (*Goniopholis*, *Pholidosaurus*, *Heterosuchus*, *Suchosaurus*). The ichthyosaurs, represented by *Ichthyosaurus*, and plesiosaurs (*Cimoliosaurus*, *Polyptychodon*) were still to be seen in the Cretaceous seas of Europe. The pterosaurs likewise continued to be inhabitants of the land, for the bones of several species of pterodactyle have been found (*Ornithocheirus*, *Pteranodon*). These remains are usually met with in scattered bones, only found at rare intervals and wide apart. In a few places, however, reptilian remains have been disinterred in such numbers from local deposits as to show how much more knowledge may yet be acquired from the fortunate discovery of other similar accumulations. One of the most remarkable of these exceptional deposits is the hard clay above referred to as filling up some deep valley-shaped depressions in the Carboniferous rocks near Bernissart in Belgium, and which has been unexpectedly encountered at a depth of more than 1000 feet below the surface in mining for coal. These precipitous defiles were evidently valleys in Cretaceous times, in which fine silt accumulated, and wherein carcases of the reptiles of the time were quietly covered up and preserved, together with remains of the river chelonians and fishes, as well as of the ferns that grew on the cliffs overhead. These deposits have remained undisturbed under the deep cover of later rocks.[2] Again, from the so-called "Cambridge Greensand"—a bed about 1 foot thick lying at the base of the Chalk of Cambridge, and largely worked for the phosphate of lime which is supplied by phosphatic nodules and phosphated fossils—there have been exhumed the remains of several chelonians, the great deinosaur *Acanthopholis*, several species of Plesiosaurs (*Cimoliosaurus*, *Polyptychodon*), 5 or 6 species of *Ichthyosaurus*, 10 species of *Ornithocheirus* —from the size of a pigeon upwards, one of them having a spread of wing amounting to 25 feet,—a crocodilian, and some others. From the same limited horizon also the bones of at least two species of birds (*Enaliornis*) have been obtained.

The most astonishing additions to our knowledge of ancient reptilian life have been made from the Cretaceous rocks of western

[1] Mantell's 'Illustrations of the Geology of Sussex,' 1827. Dollo, *Bull. Mus. Roy. Belgique*, ii. (1883). *Ann. Sci. Géol.* xvi. (1883) No. 6.

[2] E. Dupont, *Bull. Acad. Roy. Belg.* 2e sér. xlvi. (1878) p. 387. E. Van den Broeck, *Soc. Belg. Géol.* 1898, and *postea*, p. 1198.

North America, chiefly by Professors Leidy, Marsh, and Cope.[1] According to an enumeration made some years ago by Cope, but which is now below the truth, there were known 18 species of deinosaurs, 4 pterosaurs, 14 crocodilians, 13 sauropterygians or sea-saurians, 48 testudinates (turtles, &c.), and 50 pythonomorphs or sea-serpents. One of the most extraordinary of reptilian types was the *Elasmosaurus*—a huge snake-like form 40 feet long, with slim arrow-shaped head on a swan-like neck rising 20 feet out of the water. This formidable sea-monster "probably often swam many feet below the surface, raising the head to the distant air for a breath, then withdrawing it and exploring the depths 40 feet below without altering the position of its body. It must have wandered far from land, and that many kinds of fishes formed its food is shown by the teeth and scales found in the position of its stomach" (Cope). The real rulers of the American Cretaceous waters were the pythonomorphic saurians or sea-serpents, in which group Cope includes forms like *Mosasaurus*, whereof more than 40 species have been discovered. Some of them attained a length of 75 feet or more. They possessed a remarkable elongation of form, particularly in the tail; their heads were large, flat, and conic, with eyes directed partly upwards. They swam by means of two pairs of paddles, like the flippers of the whale, and the eel-like strokes of their flattened tail. Like snakes, they had four rows of formidable teeth on the roof of the mouth, which served as weapons for seizing their prey. But the most remarkable feature in these creatures was the unique arrangement for permitting them to swallow their prey entire, in the manner of snakes. Each half of the lower jaw was articulated at a point nearly midway between the ear and the chin, so as greatly to widen the space between the jaws, and the throat must, consequently, have been loose and baggy like a pelican's. The deinosaurs were likewise well represented on the shores of the American waters. Among the known forms are *Trachodon* (*Hadrosaurus*), a kangaroo-like creature resembling the *Iguanodon*, and about 28 feet long; *Diclonius*, a closely allied, perhaps identical, form with a bird-like head and spatulate beak, probably frequenting the lakes and wading there for succulent vegetable food, interesting from its occurrence in the Laramie group of beds at the very close of the Cretaceous series; and *Lælaps*, which probably also walked erect, and resembled the *Megalosaurus*. Still more gigantic was the allied *Ornithotarsus*, which is supposed to have had a length of 35 feet. There were also in later Cretaceous time strange horned deinosaurs such as *Ceratops* which, attaining a length of 25 or 30 feet, had a massive body, a pair of large and powerful horns, and a peculiar dermal armour. Akin to it were various deinosaurs united in the genus *Triceratops*, so named from the third rhinoceros-like nasal horn. Some of their skulls exceeded 6 feet in length, exclusive of the horny beak, and 4 feet in

[1] Leidy, *Smithson. Contrib.* 1865, No. 192; *Rep. U.S. Geol. and Geograph. Survey of Territories*, vol. i. (1873). Cope, *Rep. U.S. Geol. and Geograph. Survey of Territories*, vol. ii. (1875); *Amer. Naturalist*, 1878 *et seq.* Marsh, *Amer. Journ. Science*, numerous papers in 3rd series, vols. i.-lv.

width, with horn-cores about 3 feet long. *Claosaurus* was another gigantic deinosaur not unlike the *Iguanodon*, with remarkably small fore-limbs compared with the massive hind legs.[1] Pterosaurs have like-

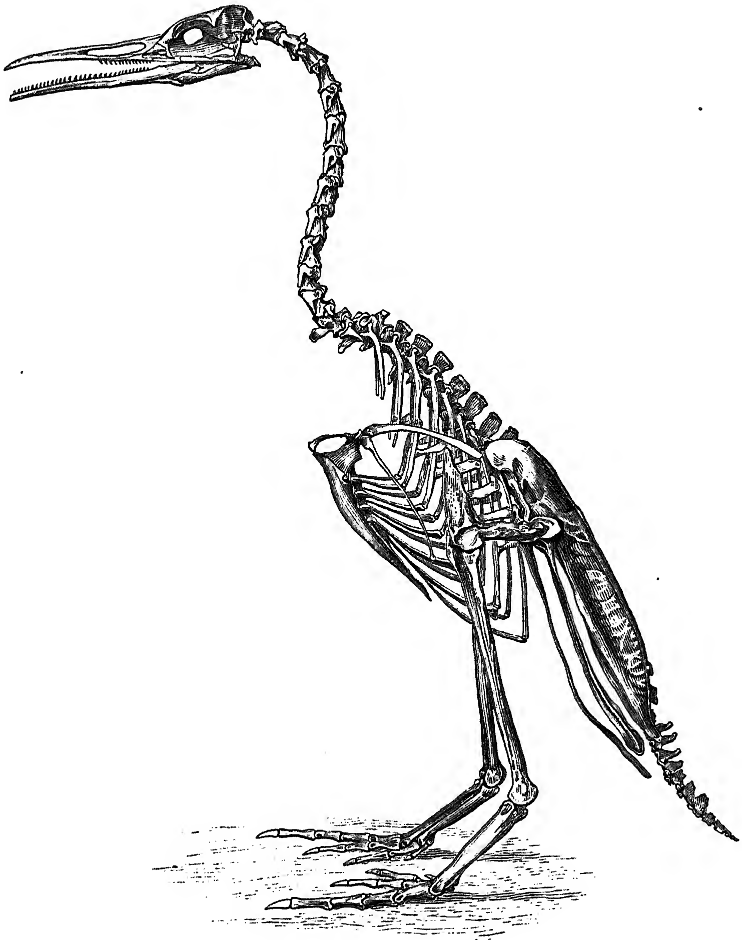


Fig. 458.—Cretaceous Bird.[2]
Hesperornis regalis, Marsh ($\frac{1}{10}$).

wise been obtained characterised by an absence of teeth (*Pteranodon*), and some of which had a spread of wing of 20 to 25 feet.[3] Among the

[1] Marsh, on Cretaceous Deinosaurs, *op. cit.* xxxvi. (1888) xxxviii. xxxix. xli. xlii. xliv. xlv. (1893). In these papers some restorations of the extinct creatures are attempted.

[2] The figure of this restoration and that in Fig. 459 were supplied to the author by the late Professor Marsh.

[3] Marsh, on American Cretaceous Pterodactyles, *Amer. Journ. Sci.* i. (1871) iii. xi. xii. xxi. xxvii. (1884).

Chelonians one gigantic species is supposed to have measured upwards of 15 feet between the tips of the flippers.

The remains of birds have been met with both in Europe and in America among Cretaceous rocks. From the Cambridge Greensand, as above noticed, bones of at least two species, referred to the genus *Enaliornis*,

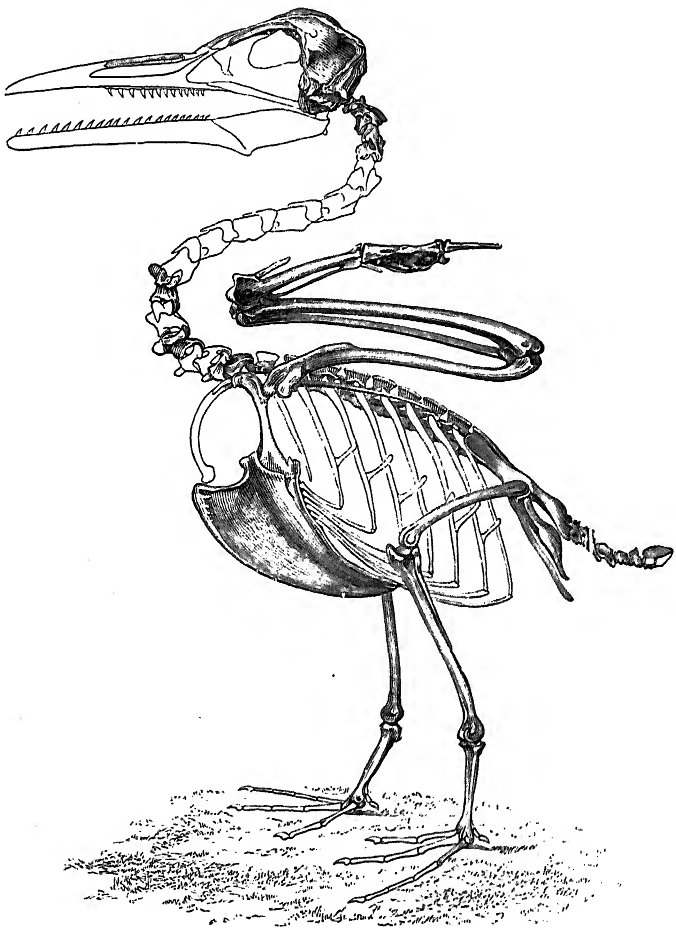


Fig. 459.—Cretaceous Bird.
Ichthyornis victor, Marsh (½).

have been obtained. These creatures are regarded by Professor Seeley as having osteological characters that place them with the existing natatorial birds.[1] From the American Cretaceous rocks nine genera and twenty species, represented by the remains of about 120 individuals, have been obtained. Among these by far the most remarkable are the

[1] *Q. J. G. S.* 1876, p. 496.

Odontornithes, or toothed birds, from the Cretaceous beds of Kansas. Professor Marsh, who described these wonderfully preserved forms, pointed out the interesting evidence they furnish of a reptilian ancestry.[1] In the most important and indeed unique genus, named by him *Hesperornis* (Fig. 458), the jaws were furnished with teeth implanted in a common alveolar groove, as in Ichthyosaurus; the wings were rudimentary or aborted, so that locomotion must have been entirely performed by the powerful hind limbs, with the aid of a broad, flat, beaver-like tail, which no doubt materially helped in steering the creature through the water. It must have been an admirable diver. Its long flexible neck and powerful toothed jaws would enable it to catch the most agile fish, while, as the lower jaws were united in front only by cartilage, as in serpents, and had on each side a joint that admitted of some motion, it had the power of swallowing almost any size of prey. *Hesperornis regalis*, the type species, must have measured about 6 feet from the point of the bill to the tip of the tail, and presented some resemblance to an ostrich. Of the other genera, *Ichthyornis* (Fig. 459) and *Apatornis* were distinguished by some types of structure pointing backward to a very lowly ancestry. They appear to have been small, tern-like birds, with powerful wings but small legs and feet. They possessed reptile-like skulls, with teeth set in sockets, but their vertebræ were bi-concave, like those of fishes. There were likewise forms which have been grouped in the genera *Graculævus*, *Laornis*, *Palæstringa*, and *Telmatornis*. Altogether the earliest known birds present characters of strong affinity with the Deinosaurs and Pterodactyles.[2]

Though mammalian remains had long been known to occur in the Triassic and Jurassic formations, none had been obtained from Cretaceous rocks, and this absence was all the more remarkable from the great abundance and perfect preservation of the reptilian forms in these rocks. But the blank was eventually filled by the remarkable discovery in the Upper Cretaceous rocks of Dakota and Wyoming of a large series of jaws, teeth, and different parts of the skeletons of small mammals belonging to many individuals, and including not a few genera and species. They were found associated with remains of deinosaurs, crocodiles, turtles, ganoid fishes, and invertebrate fossils indicating brackish or fresh-water conditions. The mammalian forms show close affinities to the Triassic and Jurassic types. There are several distinct genera of small marsupials, others seem to be allied to the monotremes, but there are no carnivores, rodents, or ungulates. The genera proposed for them by Professor Marsh are *Cimolomys*, *Cimolodon*, *Nanomys*, *Dipriodon*, *Tripriodon*, *Selenacodon*, *Halodon*, *Camptomus*, *Dryolestes*, *Didelphops*, *Cimolestes*, *Pediomys*, *Stagodon*, *Platacodon*, *Oracodon*, and *Allacodon*.[3] More recently the discovery

[1] 'Odontornithes,' being vol. i. of *Memoirs of Peabody Museum of Yale College*, and also vol. vii. of *Geol. Explor. 40th Parallel;* "Birds with Teeth," *Rep. U.S. G. S.* 1881-1882, p. 45; *Amer. Journ. Sci.* iii. (1897), on the affinities of *Hesperornis*.

[2] See Marsh, *U.S. G. S. Report*, 1881-82, p. 86.

[3] Marsh, *Amer. Journ. Sci.* xxxviii. (1889), pp. 81, 177; xliii. (1892), p. 249. Some of Marsh's genera are regarded by Prof. Osborn as having been pre-named by Cope. Thus

of a single small tooth in the Wealden series of Hastings was the first trace of mammalian life found in the Cretaceous formations of Europe. The specimen has been provisionally referred to the Purbeckian genus *Plagiaulax*.[1]

§ 2. Local Development.

The Cretaceous system, in many detached areas, covers a large extent of Europe, and includes records not only of former seas but of lakes, rivers, and dry lands. From the south-west of England it spreads across the north of France, up to the base of the ancient central plateau of that country. Eastwards it ranges beneath the Tertiary and post-Tertiary deposits of the great plain, appearing on the north side at the southern end of Scandinavia and in Denmark, on the south side in Belgium and Hanover, round the flanks of the Harz, in Bohemia and Poland, eastwards into Russia, where it covers many thousand square miles, up to the southern end of the Ural chain. To the south of the central axis in France, it underlies the great basin of the Garonne, flanks the chain of the Pyrenees on both sides, spreads out largely over the eastern side of the Spanish tableland, and reappears on the west side of the crystalline axis of that region along the coast of Portugal. It is seen at intervals along the north and south fronts of the Alps, extending down the valley of the Rhone to the Mediterranean, ranging along the chain of the Apennines into Sicily and the north of Africa, and widening out from the eastern shores of the Adriatic through Greece, and along the northern base of the Balkans to the Black Sea, round the southern shores of which it passes in its progress into Asia, where it again covers an enormous area.

Nor is the system less prominent in the New World. In North America it spreads over enormous tracts of country and displays, on a still greater scale, the same wide variety of sediments as in Europe. It runs along the eastern margin of the United States, rising from under the Tertiary formations as a narrow strip which sweeps round the southern end of the long Alleghany chain into Alabama, Mississippi, and Tennessee. On the western side of the Mississippi valley it spreads over Texas and southwards over most of Mexico. In the interior, farther north, it extends over the sites of what were probably vast sheets of fresh water, while on the Pacific slope it is largely developed in a thick series of formations which stretch northwards into British Columbia.

While there is sufficient palæontological similarity to allow a general parallelism to be drawn among the Cretaceous rocks of western Europe, there are yet strongly marked differences pointing to very distinct conditions of life, and probably, in many cases, to disconnected areas of deposit. Having regard to these geographical variations, a distinct northern and southern province, as above stated (p. 1162), can be recognised; but Gümbel has proposed a further grouping into three great regions: (1) the northern province, or area of White Chalk with *Belemnitella*, comprising England, northern France, Belgium, Denmark, Westphalia, &c.; (2) the Hercynian province, or area of *Exogyra columba*, embracing Bohemia, Moravia, Saxony, Silesia, and Central Bavaria; and (3) the southern province, or area of Hippurites, including the regions of France south of the basin of the Seine, the Alps, and southern Europe.[2]

Britain.[3]—The Purbeck beds (p. 1146) bring before us evidence of a great change in

Marsh's *Cimolomys* is said to be Cope's *Ptilodus*, and his *Dipriodon* Cope's *Meniscoëssus*. "Upper Cretaceous Mammals," *Bull. Amer. Mus. Nat. Hist.* v. (1893), p. 314.

[1] A. Smith Woodward, *Nature*, xlv. (1891), p. 164.

[2] 'Geognost. Beschreib. Ostbayer. Grenzgebirg.'

[3] Consult Conybeare and Phillips, 'Geology of England and Wales,' 1822. Fitton, *Ann. Philos.* 2nd ser. viii. 379; *Trans. Geol. Soc.* 2nd. ser. iv. 103. Dixon's 'Geology of Sussex,' edit. T. Rupert Jones, 1878. Phillips's 'Geology of Oxford and the Thames Valley.' H. B. Woodward's 'Geology of England and Wales,' 2nd edit. H. W. Bristow's 'The Isle of

the geography of England towards the close of the Jurassic period. They show how the floor of the sea, in which the thick and varied formations of that period were deposited, came to be gradually elevated, and how into pools of fresh and brackish water the leaves, insects, and small marsupials of the adjacent land were washed down. These evidences of terrestrial conditions are followed in the same region by a vast delta formation, that of the Weald, which accumulated over the south of England, while marine strata were being deposited in the north. Hence two types of Lower Cretaceous sedimentation occur, one where the strata are fluviatile (Wealden), the other where they are marine (Neocomian). The Upper Cretaceous groups, extending continuously from the coasts of Dorsetshire to those of Yorkshire, show that the diversities of sedimentation in Lower Cretaceous time were effaced by a general submergence of the whole area beneath the sea in which the Chalk was deposited. Arranged in descending order, the following are the subdivisions of the English Cretaceous rocks:[1] —

Wight,' 2nd edit. by C. Reid and A. Strahan (*Mem. Geol. Surv.*). A. Strahan's 'The Isle of Purbeck' (*Mem. Geol. Surv.*). A. J. Jukes-Browne and W. Hill, 'The Cretaceous Rocks of Britain,' vol. i. Gault and Upper Greensand (*Mem. Geol. Surv.*). Special papers on the English Cretaceous formations are quoted in subsequent footnotes.

Reference may here be made to the important memoir of A. de Grossouvre, which deals with the Chalk of all the world, "Recherches sur la Craie Supérieure," 2 vols. *Mem. Explic. Carte Géol. France*, 1901.

[1] For an explanation of the terms in the central column of this table see the footnotes on subsequent pages.

	English Stratigraphical Subdivisions.		*Palæontological Zones.*
			Danian, wanting.
	UPPER CRETACEOUS.		
Upper Chalk with flints.	Chalk of Trimingham	Senonian.	
	Chalk of Norwich, Studland Bay . .		Zone of *Belemnitella mucronata.*
	Chalk of Newhaven		Zone of *Actinocamax quadratus.*
	Chalk of Brighton, Margate, Bridlington, Salisbury		Zone of *Marsupites testudinarius.* { Upper part with *Marsupites.* Lower part with *Uintacrinus.*
	Chalk of Broadstairs, Flamborough Head Chalk of Dover		Zone of *Micraster cor-anguinum.* ,, *M. cor-testudinarium.*
Middle Chalk. (Without Flints.)	Hard nodular Chalk of Dover, &c., "Chalk Rock"	Turonian.	Zone of *Holaster planus.*
	Chalk without flints, Dover, &c. . .		,, *Terebratulina lata (gracilis).*
	Nodular Chalk of Shakespeare's Cliff, &c., "Melbourn Rock"		,, *Rhynchonella Cuvieri.*
Lower Chalk.	Grey Chalk of Folkstone, &c., Totternhoe Stone	Cenomanian.	Zone of *Holaster subglobosus* with *Actinocamax plenus* in the upper beds.
	Chalk Marl . . . . . . "Chloritic Marl," Glauconitic Marl and Cambridge Greensand . . .		Zone of *Schlœnbachia varians.*
Gault and Upper Greensand.	Warminster beds, &c.	Albian.	Zone of *Pecten asper* and *Cardiaster fossarius.*
	Upper Gault, Blackdown beds, &c. .		,, *Schlœnbachia rostrata.*
	Red Chalk of Norfolk		,, *Hoplites lautus* and *H. interruptus.*
	Lower Gault		,, *Douvilleiceras mammillatum.*

LOWER CRETACEOUS.

	Southern Type. (Fluviatile, and in upper part marine.)	*Northern Type.*[1] (Marine.)		
Lower Greensand.	Sands, clays, limestones, &c., in Kent, Surrey, Sussex, Hampshire.	Below the Red Chalk, at Speeton, on the Yorkshire coast, clays and marls, in apparently continuous sequence, pass down into Neocomian clays and shales (Speeton Clay), which are less than 300 feet thick, and shade down into Kimeridge Clay. They are grouped in four zones. Their upper portions are equivalent to the Carstone and Tealby limestone and clay of Lincolnshire, and their lower parts to the Claxby Ironstone and Spilsby Sandstone.	Aptian	4. Zone of *Belemnites minimus*, passage marls into base of Upper Cretaceous series.
				3. Zone of *Belemnites brunsvicensis* (= *semicanaliculatus*) with *B. speetonensis, absolutiformis, Jasikowi, obtusirostris, Hoplites Deshayesii, Amaltheus bicurvatus.*
Wealden.	Weald Clay.		Neocomian.	2. Zone of *Belemnites jaculum*, with *B. Jasikowi, cristatus, Olcostephanus Astieri, sulcosus, subinversus, Payeri, concinnus, speetonensis, umbonatus, Hoplites regalis, amblygonius.*
	Hastings Sands and clays, passing down into Purbeck beds.			1. Zone of *Belemnites lateralis*, with *B. russiensis, subquadratus, explanatoides, Olcostephanus* (numerous species, including *gravesiformis, polyptichus, rotula*), *Hoplites, Oxynoticeras.*

1 See G. W. Lamplugh, *Q. J. G. S.* xlv. (1889), p. 575, lii. (1896), p. 179; *Brit. Assoc.* (1890) p. 808; 'Argiles de Speeton et leurs équivalents,' by A. Pavlow and G. W. Lamplugh in *Bull. Soc. Imp. Nat. Moscou*, 1891, *Q. J. G. S.* liii. p. 542.

LOWER CRETACEOUS (NEOCOMIAN[1]).—Between the top of the Jurassic system and the stage known as the Gault, there occurs an important series of deposits to which, from their great development in the neighbourhood of Neuchâtel in Switzerland, the name of Neocomian has been given. This series, as already remarked, is represented in England by two distinct types of strata. In the southern counties, from the Isle of Purbeck to the coast of Kent, there occurs a thick series of fresh-water sands and clays termed the Wealden series. These strata pass up into a minor marine group known as the Lower Greensand, in which some of the characteristic fossils of the Upper Neocomian rocks occur. The Wealden beds of England therefore form a fluviatile equivalent of the continental Neocomian formations, while the Lower Greensand represents the later marginal deposits of the Neocomian sea, which gradually usurped the place of the Wealden estuary. The second type, seen in the tract of country extending from Lincolnshire into Yorkshire, contains the deposits of deeper water, forming the westward extension of an important series of marine formations which stretch for a long way into Central Europe.

Neocomian.[2]—The marine Neocomian strata of England are well exposed on the cliffs of the Yorkshire coast at Filey, where they occur in an argillaceous deposit long known as the Speeton Clay. This deposit is now shown to contain an interesting continuous section of marine strata from the Kimeridge Clay to the top of the Lower Cretaceous, or even into the Upper Cretaceous series. It has been carefully studied by Mr. Lamplugh and by Professors Pavlow and Nikitin, by whom it has been brought into comparison with the Neocomian rocks of Russia. The lower part of the Speeton Clay consists of hard dark bituminous shales with large septarian nodules and many crushed fossils, including species of *Perisphinctes, Olcostephanus, Belemnites, Lingula ovalis, Discina latissima, Ostrea gibbosa, Lucina minuscula,* &c. These strata are referred to the higher part of the Kimeridge Clay. They are succeeded conformably by the zone of *Belemnites lateralis*, consisting of dark, pale, and banded clays with the fossils mentioned in the foregoing table. At the base of the zone lies a "coprolite bed," and its top is taken at a "compound nodular bed" rich in fossils. The total thickness of this zone is about 34 feet. "It bridges over the space between undoubtedly Jurassic and undoubtedly Cretaceous strata." It is overlain by the zone of *Belemnites jaculum*, consisting likewise of various dark and striped clays and bands of nodules, the whole having a thickness of about 125 feet. The characteristic belemnite ranges through 120 feet of the section with hardly any trace of another species. *Olcostephanus (Astieria) Astieri* occurs in the lower part of the zone, *O. (Simbirskites) inversus* and *Payeri* in the centre and *O. (Simbirskites) speetonensis* towards the top. An interesting palæontological feature in this zone is the ocurrence of abundant tests of *Echinospatagus cordiformis*, a highly characteristic Neocomian type. The zone of *Belemnites brunsvicensis* is seldom seen in complete section, owing to the slipping of the cliffs and the detritus on the foreshore. It consists of dark clays 100 feet thick or more. Above it a few feet of mottled green or yellow clays form the top of the Speeton clay. These strata compose the zone of *Belemnites minimus*, and contain also *Inoceramus concentricus, I. sulcatus,* &c. Some of their fossils are found in the Gault, and they may thus represent here the Lower Gault, while the Red Chalk above may be the equivalent of the Upper Gault.[3]

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[1] Neocomian, from Neocomum, the old name of Neuchâtel in Switzerland.

[2] Fitton, *Trans. Geol. Soc.* 2nd. ser. iv. (1837), p. 103; *Proc. Geol. Soc.* iv. pp. 198, 208; *Q. J. G. S.* i. Consult on marine Neocomian type Young and Bird, 'Survey of the Yorkshire Coast' (1828), 2nd edit. pp. 58-64. J. Phillips, 'Geology of Yorkshire,' p. 124. J. Leckenby, *Geologist*, ii. (1859), p. 9. Bristow's 'Isle of Wight,' 2nd edit. cited on p. 1180; Judd, *Q. J. G. S.* xxiv. (1868) 218; xxvi. 326; xxvii. 207; *Geol. Mag.* vii. 220. C. J. A. Meyer, *Q. J. G. S.* xxviii. 243; xxix. 70. A. Strahan, *op. cit.* xlii. (1886) p. 486; *Mem. Geol. Surv.* sheet 84, and the 'Isle of Purbeck,' cited on p. 1181.

[3] G. W. Lamplugh, papers cited on p. 1182; and A. Pavlow, *Q. J. G. S.* lii. (1896), p. 542.

In Lincolnshire the marine Neocomian series is likewise developed. Rising to the surface from beneath the Chalk, the highest and lowest strata are chiefly sand and sandstone; the middle portion (Tealby series) clays and oolitic ironstones. According to Mr. Lamplugh, the Spilsby Sandstone and the Claxby Ironstone of this county, forming the base of the Neocomian series and resting on Upper Kimeridge shales, are equivalents of the zone of *Belemnites lateralis* at Specton. The Tealby Clay, which overlies them, is regarded as representing the zone of *B. jaculum*, the Tealby Limestone the zone of *B. brunsvicensis*, while the Carstone at the top immediately below the Red Chalk is placed on the horizon of the marls with *B. minimus*.[1] The Carstone ranges into Norfolk, and perhaps represents the entire "Lower Greensand" of central and southern England.

Wealden.[2]—In the southern counties a very distinct assemblage of strata is met with. It consists of a thick series of fluviatile deposits termed Wealden (from the Weald of Sussex and Kent, where it is best developed), surmounted by a group of marine strata ("Lower Greensand"), in which Upper Neocomian fossils occur. It would appear that the fresh-water conditions of deposit, which began in the south of England towards the close of the Jurassic period, when the Purbeck beds were laid down, continued during the whole of the long interval marked by the Lower and Middle Neocomian formations, and only in Upper Neocomian times finally merged into ordinary marine sedimentation.

Some discussion has arisen as to the correlation of this great fluviatile series. We have seen that no stratigraphical line can be satisfactorily drawn between the Purbeck and Wealden formations, which are the records of a long period of lacustrine and fluviatile conditions. It was the opinion of Fitton that all these formations should be grouped together under the name of Wealden as a series distinct from the oolites below. As, however, the evidence of fossils has accumulated, the reptiles, the fishes, and the land-plants have been claimed to present a Jurassic rather than a Cretaceous aspect. The inclusion of the Wealden formations in the Jurassic system has accordingly been strongly advocated, and this view has been adopted by some geologists.[3] On the other hand, there can be no doubt that the Wealden series passes upward into Upper Neocomian strata, and it may be presumed to represent at least in part Lower Neocomian deposits. It is unfortunate that neither in the south nor in the north of England can any satisfactory line be traced between the Jurassic and the Cretaceous systems. Until further evidence is obtained the Wealden may most conveniently be allowed to remain in the Cretaceous division.

The Wealden series has a thickness of over 2000 feet, and in Sussex and Kent consists of the following subdivisions in descending order:—

Weald Clay	1000 feet
Hastings Sand group composed of—	
3. Tunbridge Wells Sand (with Grinstead Clay) . .	140 to 380 ,,
2. Wadhurst Clay	120 ,, 180 ,,
1. Ashdown Sand (with Fairlight Clays in lower part) .	400 or 500 ,,

In the Isle of Wight these subdivisions cannot be made out, and the total visible thickness of strata (sandstones, sands, clays, and shales) is only about half of what can

[1] See G. W. Lamplugh, in papers cited on p. 1182; A. J. Jukes-Browne, "Geology of East Lincolnshire," in *Mem. Geol. Surv.* sheet 84, 1887.

[2] On the Wealden or fluviatile type consult, besides the works quoted on p. 1180, Mantell's 'Fossils of the South Downs,' 4to, 1822. Topley, "Geology of the Weald," in *Mem. Geol. Surv.* 8vo, 1875. Bristow's "Geology of the Isle of Wight," 2nd edit. (1889), in *Mem. Geol. Surv.*, gives a list of Wealden fossils at p. 258.

[3] See O. Marsh, *Amer. Journ. Sci.* i. (1896), p. 224; A. Smith Woodward, *Geol. Mag.* (1896), p. 69. A. C. Seward, *Nature*, liii. (1896), p. 462; "Catalogue of Mesozoic Plants in British Museum—the Wealden Flora" (1895), p. 240; E. van den Broeck, *Bull. Soc. Belg. Géol.* xiv. (1900). G. W. Lamplugh, *Geol. Mag.* (1900), p. 443. A. Pavlow, *Q. J. G. S.* lii.

be observed on the mainland farther east, but the base of the series is concealed. Westward, in the Isle of Purbeck, on the coast of Dorsetshire, the Wealden strata are exposed on the shore, and are estimated to be more than 2000 feet thick, but they are there beginning to thin out westward.

The sandy and clayey sediments composing the Wealden series precisely resemble the deposits of a modern delta. That such was really their origin is borne out by their organic remains, which include terrestrial plants (*Chara*, *Cladophlebis*, *Bennettites* (*Cycadeoidea*), *Tempskya*, *Equisetites*, *Fittonia*, *Microdictyon*, *Matonidium*, *Pinites*, *Rufferdia*, *Sagenopteris*, *Sphenopteris*, *Thuytes*, *Weichselia*),[1] fresh-water shells (*Unio*, *Cyrena*, *Paludina*, *Melanopsis*, &c.), with a few estuarine or marine forms, as *Ostrea*, *Exogyra*, *Mytilus*, and *Vicarya*, and ganoid fishes (*Lepidotus*), like the gar of American rivers. Among the spoils of the land floated down by the Wealden river were the carcases of huge deinosaurian reptiles, winged pterodactyles and turtles (*Goniopholis*, *Heterosuchus*, *Hylæosaurus*, *Iguanodon* (4 species), *Ornithocheirus*, *Ornithopsis*, *Pelorosaurus*, *Pholidosaurus*, *Plesiochelys*, *Cimoliosaurus*, *Polacanthus*, *Suchosaurus*, *Titanosaurus*, *Vectisaurus*). The deltoid formation, in which these remains occur, extends in an east and west direction for at least 200, and from north to south for perhaps 100 miles. Hence the delta may have been nearly 20,000 square miles in area. It has been compared with that of the Quorra; in reality, however, its extent must have been greater than its present visible area, for it has suffered from denudation, and is to a large extent concealed under more recent formations. The river probably descended from the north-west, draining a wide area, of which the existing mountain groups of Britain are perhaps merely fragments.

Professor Judd proposed the name of "Punfield Beds" for a group of strata at Punfield Cove in Swanage Bay, which he believed to bridge over the gap between the Wealden series and the Lower Greensand, and to show a gradual return of the sea, replacing the fluviatile conditions of the Wealden formations.[2] It has since been shown, however, that no such alternation of deposits exists there, but that the supposed new formation is really a part of the Lower Greensand.[3] The line of demarcation at the top of the Wealden series is always sharply defined both lithologically and palæontologically.

Lower Greensand.[4]—The Wealden series is succeeded conformably by the group of arenaceous strata which has long been known under the awkward name of "Lower Greensand." But there is here an evident break in the sedimentation, for not only are the Wealden strata sharply separable from those above them, but there are derived pebbles at the base of the overlying formation, while in Wiltshire the Lower Greensand overlaps the Wealden beds so rapidly as to indicate an actual unconformability.[5] The Lower Greensand consists mainly of yellow, grey, white, and green sands, but includes also beds of clay and bands of limestone and ironstone. At Atherfield, on the south coast of the Isle of Wight, it reaches a thickness of more than 800 feet, but thins away westward so that in 26 miles it is reduced to no more than 200 feet. It has been subdivided in descending order as under:—

Folkestone beds (Lower Albian of the Continent in the upper part)	70 to 100 feet.
Sandgate beds } (Aptian) {	75 ,, 100 ,,
Hythe beds } {	80 ,, 300 ,,
Atherfield Clay (Urgonian), resting on Wealden	20 ,, 90 ,,

[1] On the Wealden flora see Mr. Seward's 'Catalogue,' just cited, and his paper on 'La Flore Wealdienne de Bernissart,' *Mem. Mus. Roy. Hist. Nat.*, Brussels, 1900.

[2] *Q. J. G. S.* xxvii. (1871), p. 207.

[3] C. J. A. Meyer, *op. cit.* xxviii. (1872), p. 243; A. Strahan, "Geology of the Isle of Purbeck," *Mem. Geol. Surv.* (1898), p. 133.

[4] This formation was first worked out in great detail by Fitton (*Q. J. G. S.* iii. 1847, p. 289). For more recent lists of fossils see the "Geology of the Isle of Wight," *Mem. Geol. Surv.* Gregory, *Geol. Mag.* 1897, pp. 97, 187, and some of the papers cited below.

[5] 'Geology of the Isle of Wight,' p. 18.

These strata appear to represent the continental series up into the base of the Albian stage. The Atherfield Clay, well developed at Atherfield, has at its base a band of blue fossiliferous clay overlain by a highly fossiliferous seam of calcareous and ferruginous stone, the whole forming what is known as the "Perna bed," which is five or six feet thick, full of *Perna Mulleti*, and *Exogyra sinuata*. The Atherfield Clay contains an abundant assemblage of fossils, among which are *Hoplites Deshayesii*, *Nautilus requinianus*, *Ancyloceras matheronianum*, *Aporrhais Robinaldina*, *Arca Raulini*, *Exogyra Boussingaulti*, *Plicatula placunea*, *Anomia lævigata*, *Terebratula sella*, *Rhynchonella depressa*. In the Hythe beds are found *Hoplites Deshayesii*, *Douvilleiceras cornuelianum*, *Macroscaphites gigas*, *M. Hilsii*, *Crioceras Bowerbankii*, *Belemnites semicanaliculatus*, *Plicatula placunea*. Some of these fossils occur also in the Sandgate beds, while the upper part of the Folkestone beds yields likewise *Douvilleiceras mamillatum*. The Hythe and Sandgate beds may therefore represent the Aptian stage, while the Folkestone subdivision may be regarded as the equivalent of the lower part of the Albian. The "Bargate beds" of Surrey, which may be on the same horizon as those of Sandgate, consist of about 25 feet of sands, siliceous layers, limestone and clays, which have yielded no fewer than 34 genera and 139 species of foraminifera.[1] Again in Surrey the sandy strata above the Atherfield Clay include cherty bands full of sponge-spicules.[2]

Of the total assemblage of fossils in the "Lower Greensand," only a small proportion passes up into the Upper Cretaceous formations, except among the foraminifera, of which nearly 70 species are common to the two series. This marked palæontological break, taken in connection with a great lithological change, and with an unconformability which in Dorset brings the Gault directly upon the Kimeridge Clay, shows that a definite boundary line can be drawn between the lower and upper parts of the Cretaceous system in the south of England.

Upper Cretaceous.[3]—Three leading lithological groups have long been recognised as constituting the Upper Cretaceous series of England. First, a band of clay termed the "Gault"; second, a variable and inconstant group of sands and sandstones called the "Upper Greensand"; and, third, a massive calcareous formation known as the Chalk. The progress of palæontological and stratigraphical investigation, and more especially the development of the system of classification by zones has led to a subdivision of these three types into minor stages and substages, generally though not always defined by lithological distinctions and more especially characterised by peculiar assemblages of fossils. It is now possible by this means to place the English formations on parallel lines with their representatives on the continent.

Gault and Upper Greensand[4] (Albian).—The Gault was formerly believed always to underlie the Upper Greensand. It has now been ascertained, however, that the greater part of the Gault so well developed at Folkestone and the greater part of the Upper Greensand are really equivalents of each other, formed contemporaneously under different conditions of sedimentation.[5] Mr. Jukes-Browne has accordingly proposed to group the two formations together under the name of Selbornian.[6]

The Gault is a dark, stiff, blue, sometimes sandy or calcareous clay, with layers of pyritous and phosphatic nodules and occasional seams of greensand. It varies from 100 to more than 300 feet in thickness, forming a marked line of boundary between the Upper and Lower Cretaceous rocks, overlapping the latter and resting sometimes even

1 F. Chapman, *Q. J. G. S.* (1894), p. 677.

2 T. Leighton, *Q. J. G. S.* li. (1895), p. 104.

3 This important series of formations is described in full detail by A. J. Jukes-Browne and W. Hill in vols. i. and ii. of the "Cretaceous Rocks of Britain," *Mem. Geol. Surv.*

4 "Gault" is a Cambridgeshire provincial name.

5 This view was expressed more than fifty years ago by Godwin Austen, *Q. J. G. S.* vi. (1850), pp. 461, 472.

6 "Cretaceous Rocks of Britain," vol. i. (1900), pp. 1, 30.

on the Kimeridge Clay. The best section of this formation is that of Copt Point, near Folkestone, where the following subdivisions have been established by Messrs. De Rance and Price :[1]—

Base of Cenomanian.

Upper Gault	Zone of *Schlœnbachia rostrata.*	Pale grey marly clay (56 ft. 3 in.), characterised by *Schlœnbachia rostrata, S. Goodhalli, Ostrea frons, Inoceramus Crispii.*
		Hard pale marly clay (5 ft. 1 in.), with *Schlœnbachia rostrata, Kingena lima, Plicatula gurgitis, Pentacrinus Fittoni, Cidaris gaultina.*
		Pale grey marly clay (9 ft. 4½ in.), with *Schlœnbachia rostrata, S. varicosa, Scaphites hugardianus, Inoceramus sulcatus, Pholadomya fabrina, Pleurotomaria Gibbsii.*
		Darker clay, with two lines of phosphatic nodules and rolled fossils (9½ in.), with *Desmoceras Beudanti, Schlœnbachia cristata, S. brongniartiana, Acanthoceras itierianum, Murex calcar, Scalaria gaultina, Pholadidea Rhodani, Pecten Robinaldinus, Cyprina quadrata.*
Lower Gault	Zone of *Hoplites lautus.*	Dark clay (6 ft. 2 in.), highly fossiliferous, with *Hoplites auritus, Nucula bivirgata, Buccinum gaultinum, Aporrhais Parkinsoni, Fusus indecisus.*
		Dark mottled clay (1 ft.), *Hoplites denarius, Schlœnbachia cornuta, Turrilites hugardianus, Necrocarinus Bechei.*
		Dark spotted clay (1 ft. 6 in.) *Hoplites lautus, H. raulinianus, Astarte dupiniana, Solarium moniliferum, Phasianella ervyana,* numerous corals.
		Paler clay (4 in.) *Schlœnbachia Delaruei, Natica obliqua, Dentalium decussatum, Fusus rusticus.*
		Light fawn-coloured clay, "crab-bed" (4 ft. 6 in.) with numerous carapaces of crustaceans (*Palæocorystes Stokesii, P. Broderipii*), *Pinna tetragona, Hamites attenuatus, Corbula elegans.*
		Dark clay marked by the rich colour of its fossils (4 ft. 3 in.), *Hoplites auritus, Turrilites elegans, Ancyloceras spinigerum, Aporrhais calcarata, Fusus itierianus, Cerithium trimonile, Corbula gaultina.*
	Zone of *Hoplites interruptus.*	Dark clay, dark greensand, and pyritous nodules (10 ft. 1 in.), *Hoplites interruptus, Hamites attenuatus, Crioceras astierianum, Belemnites minimus.*
	Zone of *Douvilleiceras mammillatum.*	Greensand, coarse in places, mixed with dark clay above (2½ feet) resting on a coarse gritty band partly indurated into large concretionary masses with dark phosphatic nodules (1 foot) with a yellowish incoherent greensand underneath (3 feet).

Folkestone Beds.

Mr. Price remarked that, out of 240 species of fossils collected by him from the Gault, only 39 are common to the lower and upper divisions, while 124 never pass up from the lower and 59 appear only in the upper. The Lower Gault seems to have been deposited in a sea specially favourable to the spread of gasteropods, of which 46 species occur in that division of the formation. Of these only six appear to have survived into the period of the Upper Gault, where they are associated with five new forms. Of the lamellibranch fauna, numbering in all 73 species, 39 are confined to the lower division, four are peculiar to the passage-bed (No. 8), 14 pass up into the upper division, where they are accompanied by 16 new forms. About 46 per cent of the Gault fauna pass up into the Upper Greensand.[2]

[1] C. E. de Rance, *Geol. Mag.* v. p. 163 ; i. (2) p. 246. F. G. H. Price, *Q. J. G. S.* xxx. p. 342 ; 'The Gault,' 8vo, London, 1879. See also Mr. Jukes-Browne, "Cretaceous Rocks of Britain," *Mem. Geol. Surv.* vol. i. p. 73.

[2] The foraminifera of the Gault at Folkestone, with reference to the zones here given,

According to the view above referred to as proposed by Mr. Jukes-Browne, the Gault of the Folkestone section, 112 feet in thickness, contains the whole of his "Selbornian" stage, that is, the upper part of the section is the equivalent of what is elsewhere the sandy series known as "Upper Greensand." At one time a sandy glauconitic marl which overlies the Gault at Folkestone was regarded as Upper Greensand. This identification naturally strengthened the belief of the posteriority of the latter formation. It is now generally agreed, however, that the marl in question is really the so-called "Chloritic Marl" at the base of the Cenomanian stage.

As the Gault is followed westwards from the Isle of Wight it gradually diminishes in thickness until in Devonshire it appears to be represented by a few feet of greensand. At the same time it is overlain by a progressively increasing depth of sandy strata, which have long been known as the Upper Greensand. There can now be no doubt that these arenaceous deposits were coeval with and strictly represent the argillaceous deposits of the south-eastern counties. The Upper Gault is characterised by the occurrence of *Schlœnbachia rostrata,* and this ammonite serves as a useful guide among the more sandy strata farther west. The zone is probably thickest in the Isle of Wight (about 130 feet). It there consists of greenish glauconitic sandstones with conspicuous layers of black and grey chert in the upper part. Some of those finer arenaceous strata are known as "Malmstone" or "Malm Rock," which may be defined as "a fine-grained siliceous rock, the silica of which is principally of the colloid variety, either in the form of a semigranular groundmass or of scattered microscopic spheroids or in both forms. Sponge spicules, or the spaces once occupied by them, are always abundant and seem to have supplied the silica which is now in the globular or semigranular condition."[1] Small quantities of quartz, mica and glauconite are present with some calcareous matter. Where the lime increases to 20 or 25 per cent the rock is known as calcareous malmstone or "Firestone." The malmstone passes into a micaceous sandstone containing quartz, mica, glauconite, sponge spicules and globular silica—the "Gaize" of French geologists. With its associated beds of firestone and gaize the malmstone covers a large tract of surface in southern England, and as it extends under the Chalk and Tertiary formations Mr. Jukes-Browne computes that the portion of it which remains after extensive denudation has an area of nearly 4000 square miles.

Besides these more solid constituents which, owing to their greater hardness, give rise to such picturesque landscapes as those above the undercliff of the Isle of Wight; the Upper Greensand in that island and in the south-western counties consists in large measure of fine soft sands, composed mainly of quartz with some mica and a constant admixture of glauconite, which gives the prevailing tint of greyish-green to the deposits. These sands, however, are here and there indurated into hard calcareous sandstones and lenticular concretions or "doggers."

The fossils of the Upper Gault and Upper Greensand or zone of *Schlœnbachia rostrata* have been collected mainly at Folkestone and Cambridge.[2] Those yielded by the Malmstone and Gaize come chiefly from these strata as seen around Devizes, while those

have been described by F. Chapman, *Journ. R. Micros. Soc.* 1891, p. 565; 1892, pp. 321, 749. See also the list of fossils in vol. i. of the *Geol. Surv. Memoir* on the "Cretaceous Rocks of Britain," p. 481.

[1] A. J. Jukes-Browne, 'Cret. Rocks of Britain,' vol. i. p. 54.

[2] The so-called Greensand of Cambridge (pp. 1175, 1182), a thin glauconitic marl, with phosphatic nodules and numerous erratic blocks, was formerly classed with the Upper Greensand, but has been shown to be the equivalent of the Glauconitic Marl, forming really the base of the Chalk Marl and lying unconformably upon the Gault, from the denudation of which its rolled fossils have been derived. Jukes-Browne, *Q. J. G. S.* xxxi. p. 272, xxxiii. p. 485, xliii. p. 545. "Geology of Cambridge," by W. H. Penning and A. J. Jukes-Browne, *Mem. Geol. Surv.* (1881), p. 24. The fishes of the deposit are enumerated by A. Smith Woodward, *Geol. Mag.* (1895), p. 207.

of the sands have been supplied from the Isle of Wight and the deposits in Dorset and Devon, particularly in the Blackdown Hills.[1] Besides the distinguishing ammonites and those mentioned in the table on p. 1182, the fossils include *Hoplites auritus, H. raulinianus, Anisoceras (Hamites) armatum, Turrilites Bergeri, Aporrhais Parkinsoni, Cardium gentianum, Cucullæa glabra, Trigonia aliformis, Terebratula biplicata, Rhynchonella sulcata.*

At the highest part of the Upper Greensand, where fully developed, there lies a group of sandy strata, 10 to 60 feet thick, which in lithological characters and in fossil contents differs from the deposits underneath them. As they are well developed in the Vale of Warminster, Wiltshire, they have long been known as the "Warminster Beds." At that locality they are about 18 feet thick, and consist of glauconitic sands, chert, and siliceous rock, composed largely of spicules. These strata form the zone of *Pecten asper* and *Cardiaster fossarius.* Among their other fossils are numerous lamellibranchs (*Lima semiornata, Pecten Robinaldinus*), brachiopods (*Rhynchonella dimidiata, R. grasiana, Terebratula biplicata, T. ovata, Terebrirostra lyra*), polyzoa (*Ceriopora polymorpha*), echinoderms (more than 30 species, including *Cidaris, Catopygus, Peltastes, Pseudodiadema, Salenia*) and sponges.[2]

At Hunstanton in Norfolk, likewise in Lincolnshire and Yorkshire, as already (p. 1183) referred to, the "Red Chalk"—a ferruginous, hard, nodular chalk zone (4 feet), lies at the base of the Chalk and rests on the Upper Neocomian "Carstone," the true Gault being there absent, although it occurs a few miles farther south.[3] The proper horizon of this band has been the subject of much discussion; but it probably represents the Gault. Bands of red and yellow chalk occur in the lower parts of the Chalk above the horizon of the Red Chalk in Lincolnshire and Suffolk.[4]

Lower Chalk (Cenomanian).[5]—The thick calcareous deposit known as the Chalk is now classed in three chief divisions—Lower, Middle, and Upper, corresponding to

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[1] On the literature of the "Blackdown beds," see W. Downes, *Q. J. G. S.* xxxviii. (1882), p. 75, where a list of their fossils is given. The numerous corals of the deposit were described by P. Martin Duncan, *op. cit.* xxxv. p. 90.

[2] A. J. Jukes-Browne, *op. cit.* pp. 62, 238, and authorities there cited.

[3] See Whitaker, *Geol. Mag.* 1883, p. 22; *Proc. Geol. Assoc.* viii. No. 3 (1883), p. 133. This author gives a full description and bibliography of the Red Chalk in *Proc. Norwich Geol. Soc.* i. Part vii. (1883), p. 212. See also Mr. Lamplugh's papers cited *ante*, p. 1182, who shows that the Red Chalk belongs to the zone of *Belemnites minimus.*

[4] A. J. Jukes-Browne, *Geol. Mag.* 1887, p. 24. W. Hill and Jukes-Browne, *Q. J. G. S.* xliii. p. 544.

[5] For a comparison and discussion of this stage in the south of England and in France see A. J. Jukes-Browne and W. Hill, *Q. J. G. S.* lii. (1896), pp. 99-177. The name of the stage is derived from Cœnomanum, the old Latin name of the town Mans in the department of Sarthe. To the illustrious Hébert geology is indebted for inaugurating the thorough detailed study and classification to which the Upper Cretaceous formations of the Anglo-Parisian basin have been subjected. In 1874 he published a short memoir, in which the Chalk in Kent was subdivided into zones equivalent to those in the Paris basin (*Bull. Soc. Géol. France*, 1874, p. 416). Subsequently the same task was taken up and extended over the rest of the English Cretaceous districts by Dr. Charles Barrois ('Recherches sur le Terrain Crétacé supérieur de l'Angleterre et de l'Irlande,' Lille, 1876). The first English geologist who appears to have attempted the palæontological subdivision of the Chalk was Mr. Caleb Evans ('Sections of Chalk,' Lewes, 8vo, 1870; *for the Geologists' Association*). See also W. Whitaker, 'Geology of the London Basin' and 'Geology of London'; Bristow's 'Isle of Wight,' 2nd edit.; and A. Strahan's "Isle of Purbeck," in *Geol. Survey Memoirs.* A tolerably full bibliography will be found in Dr. Barrois' volume, and the whole subject is fully discussed in vols. i. and ii. of the Geological Survey Memoir on the "Cretaceous Rocks of Britain."

the Cenomanian, Turonian, and Senonian stages of the Continent. Under the name of Lower Chalk are included the groups of the "Glauconitic" or "Chloritic Marl," the "Chalk Marl," and the "Grey Chalk" up to the top of the zone of *Actinocamax plenus* and base of the "Melbourn Rock."

Glauconitic (Chloritic) Marl.—This name has been applied to a local white, or light yellow, chalky marl lying at the base of the Chalk, and marked by the occurrence of grains of glauconite (not chlorite) and phosphatic nodules. It varies up to 15 feet in thickness. Among its fossils are *Acanthoceras laticlavium, A. Mantelli, Schlœnbachia Coupei, S. varians, Nautilus sublævigatus, Turrilites tuberculatus, Solarium ornatum, Plicatula inflata, Terebratula biplicata.* It forms the base of the *Schlœnbachia varians* zone.

Chalk Marl is the name given to an argillaceous chalk forming with the Chloritic marl, where the latter is present, the base of the true Chalk formation. This subdivision is well exposed on the Folkestone cliffs, also westward in the Isle of Wight, where a thickness of upwards of 100 feet has been assigned to it. Among its characteristic fossils are *Plocoscyphia labrosa, Holaster lævis, Terebratulina triangularis, Rhynchonella Martini, R. Mantelliana, Ostrea vesicularis, Inoceramus latus, I. striatus, Lima globosa, Plicatula inflata, Acanthoceras cenomanense, A. Mantelli, A. navicularis, Hoplites falcatus, Schlœnbachia varians, Scaphites æqualis, Turrilites costatus.*

Careful chemical and microscopic examination of the various subdivisions of the Chalk have disclosed the presence, even in the white and apparently perfectly pure Chalk, of a small proportion of inorganic mineral matter, giving rise to residues in which a number of minerals can be discriminated, including quartz, felspar, mica, hornblende, augite, tourmaline, zircon, rutile, anatase, brookite, garnet, &c. In the Chalk-marl the total amount of mineral residue is about 40 per cent, and in the Grey Chalk 44 per cent, while in the white Upper Chalk it has been found to sink to little more than a half of 1 per cent.[1]

Grey Chalk.—The lower part of the Chalk has generally a somewhat greyish tint, often mottled and striped. In Bedfordshire and adjoining counties a band of hard grey sandy chalk, from 6 to 15 feet thick, containing 8 per cent of silica and in places much glauconite, is known as the "Totternhoe Stone,"[2] and forms the base of the Grey Chalk, which as a stage comprises the palæontological zone of *Holaster subglobosus* with *Actinocamax plenus* in its upper portion. In Cambridgeshire the Chalk Marl is covered by the band of Totternhoe Stone passing up into sandy and then nearly pure white chalk, and these strata, equivalents of the Grey Chalk, are probably separated by a palæontological and stratigraphical break from the next overlying (Turonian) member of the series.[3] According to the original classification of M. Hébert, this zone of *Actinocamax plenus* is placed at the base of the Turonian group; by Dr. Barrois it is made the summit of the Cenomanian. The latter view receives support from traces of a break and denudation above this zone in England.

The Lower Chalk attains its fullest development along the shore-cliffs of Kent, where it has a thickness of about 200 feet. According to Mr. F. G. H. Price,[4] it is there divisible into five beds or sub-stages. Of these the lowest, 8 feet thick (=lower part of the *Schlœnbachia varians* zone), contains among other fossils *Discoidea subucula, Pecten Beaveri, Schlœnbachia varians;* the second bed (11 feet) contains many fossils, including *Acanthoceras rothomagense, A. Mantelli, Pachydiscus lewesiensis* (=part of

[1] Dr. Hume's Essay cited on p. 1162, and M. Cayeux's volume.

[2] For the list of fossils of this bed in Norfolk and Suffolk see Jukes-Browne and W. Hill, *Q. J. G. S.* 1887, p. 577.

[3] A. J. Jukes-Browne, *Geol. Mag.* 1880, p. 250. See also the same author in "Geology of the Neighbourhood of Cambridge" (*Mem. Geol. Surv.*), and *Q. J. G. S.* 1886, p. 216; 1887, p. 544.

[4] *Q. J. G. S.* xxiii. p. 436.

Schlœnb. varians zone) ; the third bed (2 feet 9 inches), also abundantly fossiliferous, contains among other forms *Peltastes clathratus*, *Hemiaster Morrisii*, *Terebratulina rigida*, *Rhynchonella mantelliana*, *Acanthoceras rothomagense*, *Schlœnb. varians;* this and the two underlying beds are regarded as comprising the zone of *Acanthoceras rothomagense* and *Schlœnb. varians;* the fourth sub-stage or zone of *Holaster subglobosus* (148 feet), contains among its most characteristic fossils *Discoidea cylindrica*, *Holaster subglobosus*, and in its upper part *Actinocamax plenus;* the fifth bed, or zone of *Actin. plenus*, consisting of yellowish-white gritty chalk (4 feet), forms a well-defined band between the Grey Chalk and the overlying lower subdivision of the White Chalk (Turonian) ; it contains few fossils, among which are *Actin. plenus*, *Radiolites Mortoni*, *Ptychodus*.

Middle Chalk (Turonian).[1]—This division comprises the "Lower White Chalk with few flints," and is marked off at the base by a band of hard yellow and white nodular chalk, locally known in Cambridgeshire as "rag," and termed by geologists the "Melbourn Rock." It is about 8 or 10 feet thick, and forms a convenient band in mapping out the subdivisions of the Chalk. It contains *Rhynchonella Cuvieri*, *Terebratulina striata*, *Inoceramus Cuvieri*, *Spondylus striatus*, *Pachydiscus peramplus*, &c.[2]

The White Chalk of England and north-west France forms one of the most conspicuous members of the great Mesozoic suite of deposits. It can be traced from Flamborough Head in Yorkshire across the south-eastern counties to the coast of Dorset. Throughout this long course, its western edge usually rises somewhat abruptly from the plains as a long winding escarpment, which from a distance often reminds one of an old coast-line. The upper half of the deposit is generally distinguished by the presence of many nodular layers of flint. With the exception of these enclosures, however, the whole formation is a remarkably pure white pulverulent dull limestone, meagre to the touch, and soiling the fingers. Composed mainly of crumbled foraminifera, urchins, mollusks, &c., like some of the foraminiferal ooze of the existing sea-bed, it must have been accumulated in a sea tolerably free from sediment. There is, however, no evidence that the depth of the water at all approached that of the abysses in which the present Atlantic globigerina-ooze is being laid down. Indeed, the character of the foraminifera, and the variety and association of the other organic remains, are not like those which have been found to exist now on the deep floor of the Atlantic, but present rather the characters of a shallow-water fauna.[3] Moreover, the researches of M. Hébert have shown that the Chalk is not simply one continuous and homogeneous deposit, but contains evidence of considerable oscillations, and even perhaps of occasional emersion and denudation of the sea-floor on which it was laid down. The same observer believed that enormous gaps occur in the Upper Cretaceous series of the Anglo-Parisian basin, some of which are to be supplied from the centre and south of France (*postea*, p. 1198).

Following the modern classification, we find that the old subdivision of "Chalk with few flints" agrees on the whole with the Turonian section of the system. This division, as above remarked, appears in some places to lie unconformably upon the members below it, from which it is further separated by a marked zoological break. Nearly all the Cenomanian species now disappear, save two or three cosmopolitan forms. The echinoderms and brachiopods are entirely replaced by new species.[4] Not only is

[1] From Touraine, where the marly chalk is well developed.

[2] W. Hill and A. J. Jukes-Browne, *Q. J. G. S.* 1886, p. 216 ; 1887, p. 580. W. Hill, *op. cit.* 1886, p. 232.

[3] Dr. J. Gwyn Jeffreys pointed out that the mollusca of the Chalk indicate comparatively shallow-water conditions ; *Brit. Assoc. Rep.* 1877, Secs. p. 79. See also *Nature*, 3rd July 1884, p. 215 ; L. Cayeux, *Ann. Soc. Géol. Nord.* xix. (1891), pp. 95, 252. For a general account of the origin of the Chalk, with special reference to its minuter organisms, see T. R Jones, *Trans. Hertford. Nat. Hist. Soc.* iii. Part 5 (1885), p. 143.

[4] Jukes-Browne, *Geol. Mag.* 1880, p. 250.

the base of the Turonian group defined by a stratigraphical hiatus, but its summit is marked by the "Nodular Chalk" of Dover and the hard "Chalk Rock," which appear to indicate another stratigraphical break in what was formerly believed to be an uninterrupted deposit of chalk. The three Turonian palæontological zones, so well established in France, are also traceable in England. As exposed in the splendid Kent cliffs, the base of the English beds is formed by a well-marked band (32 feet) of hard gritty chalk, made up of fragments of *Inocerami* and other organisms.[1] Fossils are here scarce; they include *Inoceramus mytiloides* (which begins here), *Rhynchonella Cuvieri*, *Galerites* (*Echinoconus*) *subrotundus*, *Cardiaster pygmæus*. Above this basement bed lies the massive Chalk without flints, full of fragments of *Inoceramus mytiloides*, with *I. Cuvieri*, *Terebratula semiglobosa*, *Terebratulina lata*, *Galerites* (*Echinoconus*) *subrotundus*, &c. The lower 70 feet or so include the zone of *Rhynchonella Cuvieri*, the next 90 or 100 feet that of *Terebratulina lata*, and the upper 50 or 60 feet, containing layers of black flints, that of *Holaster planus*. At the top comes the remarkably constant band of hard cream-coloured limestone known as the "Chalk Rock," varying from a few inches to 10 feet in thickness. Its upper surface is generally well defined, sometimes even suggestive of having been eroded, but it shades down into the Lower Chalk.[2] This band has yielded a large assemblage of fossils, including *Nautilus sublævigatus*, *Heteroceras reussianum*, *Baculites bohemicus*, *Prionocyclus Neptuni*, *Pachydiscus peramplus*, *Scaphites Geinitzi*, *Crioceras ellipticum*, species of *Emarginula*, *Pleurotomaria*, *Trochus*, *Turbo*, *Cerithium*, *Aporrhais*, and other gasteropods, together with *Septifer lineatus*, *Inoceramus striatus*, *Lima Hoperi*, *Spondylus spinosus*. *Cyprina quadrata*, *Cuspidaria caudata*, &c.[3]

From the several subdivisions of the English Chalk a considerable number of species and genera of fossil fishes have been obtained. They embrace selachians (*Notidanus*, *Hybodus*, *Drepanephorus*, *Acrodus*, *Oxyrhina*, *Lamna*, *Corax*, *Scylliodus*, *Ptychodus*), chimæroids (*Edaphodon*, *Ischyodus*, *Elasmodectes*), ganoids (*Macropoma*, *Lophiostomus*, *Cœlodus*, *Anomæodus*, *Protosphyræna*), and teleosteans (*Portheus*, *Ichthyodectes*, *Pachyrhizodus*, *Osmeroides*, *Hoplopteryx*).[4]

Dr. A. W. Rowe has recently shown the remarkable value of the species of *Micraster* for purposes of zonal determination. He has traced an unbroken evolution of variations in this genus from the base of the Turonian up to the top of the *Micraster* zones of the Senonian stage, and has found that in each zone the special features of this development are so distinctly marked that they may be confidently used to fix the zone from which any specimen of *Micraster* has been obtained. The zone of *Terebratulina lata* is marked by the occurrence of *Micraster cor-bovis*, the only *Micraster*, with rare exceptions, found below the level of the zone of *Holaster planus*. The latter zone is distinguished by *M. Leskei*, *præcursor* and *cor-testudinarium*. But besides these specific forms Dr. Rowe has been able to discriminate varieties which he has arranged into groups, based on a minute comparison of differences in the test.[5]

Upper Chalk (Senonian,[6] *Upper Chalk with many flints*).—This massive formation is composed of white, pulverulent, and usually tolerably pure chalk, with scattered flints, which, being arranged in the lines of deposit, serve to indicate the otherwise indistinct stratification of the mass. It has been generally regarded by English geologists as a single formation, with great uniformity of lithological characters and fossil contents.

[1] For an account of the Middle Chalk of Dover see W. Hill, *Q. J. G. S.* 1886, p. 232.

[2] Whitaker, *Mem. Geol. Surv.* iv. p. 46; Jukes-Browne, *Geol. Mag.* 1880, p. 254. A similar band occurs in Normandy.

[3] H. Woods, *Q. J. G. S.* lii. (1896), p. 68; liii. (1897) p. 377.

[4] A. Smith Woodward, *Proc. Geol. Assoc.* x. p. 285.

[5] *Q. J. G. S.* lv. (1899), p. 494; *Proc. Geol. Assoc.* xvi. Part vi. (1900), xvii. Part i. (1901).

[6] From Sens, in the department of Yonne.

Mr. Whitaker, however, showed that distinct lithological platforms occur in it, and later researches, especially by MM. Hébert and Barrois, brought to light in it the same zones that occur in the Paris basin. Of these the lowest, or that of the Micrasters (Broadstairs and St. Margaret's Chalk), is most widely spread, the others having suffered most from denudation. It is well exposed along the cliffs of Kent at Dover, and also in the Isle of Thanet. At Margate its thickness has been ascertained by boring to be 265 feet. It contains two zones, in the lower of which the characteristic urchin is *Micraster cor-testudinarium*, while in the upper it is *M. cor-anguinum*. Near the top of the Micraster group of beds in the Isle of Thanet[1] lies a remarkable seam of flint about three or four inches thick, forming a nearly continuous floor, which has been traced southwards at the top of the cliffs between Deal and Dover. Again, on the coast of Sussex, what may be nearly the same horizon in the chalk is defined by a corresponding band of massive flattened flints. The traces of immersion and erosion observed by M. Hébert in the Paris Chalk are regarded by Dr. Barrois as equally distinct on the English side of the Channel, in the form of surfaces of hardened and corroded chalk. One of these surfaces marks the upper limit of the Micraster group on the Sussex coast, where it consists of a band of yellowish, hardened, and corroded chalk about six inches thick, containing rolled green-coated nodules of chalk.[2] A similar hardened, corroded band forms the same limit in the Isle of Thanet. Occasional lenticular layers and pipes of phosphatic chalk are found in this stage, but in England hitherto only on a small scale.[3] Among the fossils of the Micraster division the following may be mentioned: *Micraster cor-testudinarium*, *M. cor-anguinum*, *Cidaris clavigera*, *Echinocorys vulgaris*, *Galerites* (*Echinoconus*) *conicus*, *Epiaster gibbus*, *Terebratulina lata*, *Terebratula semiglobosa*, *Ostrea vesicularis*, *Inoceramus involutus*.

The middle subdivision, or Margate Chalk, has been named the Marsupite zone by Dr. Barrois, from the abundance of these crinoids. It attains a thickness of about 80 feet in the Isle of Thanet, where it contains few or no flints, and upwards of 400 feet in the Hampshire basin, where flints are numerous. Among its fossils are *Porosphærea globularis*, *Bourgueticrinus ellipticus*, *Marsupites testudinarius*, *Micraster coranguinum*, *Galerites* (*Echinoconus*) *conicus*, *Echinocorys vulgaris*, *Cidaris clavigera*, *C. sceptrifera*, *Thecidium Wetherelli*, *Terebratula semiglobosa*, *Rhynchonella plicatilis*, *Terebratulina striata*, *Spondylus spinosus*, *S. dutempleanus*, *Pecten cretosus*, *Ostrea vesicularis*, *O. hippopodium*, *Inoceramus lingua* (and several others), *Actinocamax verus*, *A. Merceyi*, *Pachydiscus leptophyllus*. The lower half of the Marsupite zone is distinguished by the presence of *Uintacrinus*—a free-swimming crinoid.[4]

The highest remaining group, or Norwich Chalk, forms the *Belemnitella* zone so well marked in northern Europe. It attains a thickness of from 100 to 160 feet in the Hampshire basin, is absent from that of London, but reappears in Norfolk, where it attains its greatest development. It is at Norwich a white crumbling chalk with layers of black flints which have yielded abundant sponge-spicules.[5] Among its fossils are *Parasmilia centralis*, *Cœlosmilia laxa*, *Cyphosoma magnificum*, *Salenia geometrica*, *Echinocorys vulgaris*, *Rhynchonella plicatilis*, var. *octoplicata*, *R. limbata*, *Terebratula carnea*, *T. obesa*, *Ostrea lunata*, *Belemnitella mucronata*.

The uppermost, or Danian,[6] division of the Continental Chalk appears to be absent in England, unless its lower portions are represented by some of the uppermost beds of

[1] F. A. Bedwell, *Geol. Mag.* 1874, p. 16.

[2] Barrois, 'Terrain Crétacé de l'Angleterre,' &c. 1876, p. 21.

[3] A. Strahan, *Q. J. G. S.* xlvii. (1891), p. 356; *Geol. Mag.* (1895), p. 336; *Q. J. G. S.* lii. (1896), p. 463.

[4] For description and figures of this remarkable crinoid, see Bather, *Proc. Zool. Soc.* (1895) p. 974, and Springer, *Mem. Mus. Zool. Harvard*, xxv. (1901).

[5] Professor Sollas, *Ann. Mag. Nat. Hist.* vi. (1880), pp. 384, 437.

[6] So named from its development in Denmark.

the Norwich Chalk. The highest beds of the English Chalk appear on the Norfolk coast, at Trimingham, near Cromer, and contain *Ostrea lunata*, *Pecten pulchellus*, *Terebratulina gracilis* (type), *Trigonosemus elegans*, and many polyzoa.

The Cretaceous system is sparingly represented in Ireland and Scotland. Under the Tertiary basaltic plateau of Antrim, and resting unconformably on Liassic and Rhætic strata,[1] there lies an interesting series of deposits (from 70 to more than 200 feet thick) which in lithological aspect differ greatly from their English equivalents, and yet from their fossil contents can be satisfactorily paralleled with the latter. They are thus arranged :—

Hard white chalk 65 to 200 feet, with *Echinocorys sulcatus*, &c.	= zone of *Belemnitella mucronata*.	Senonian.
Spongiarian bed (Ventriculites, &c.) . . .	,, *Actinocamax verus*	
Glauconitic (Chloritic) Chalk	,, *Echinocorys gibbus* and *Camerospongia fungiformis*, representing the *Micraster coranguinum* and part of the *Marsupites* or *Actinocamax verus*-zones.	
Glauconitic (Chloritic) sands	,, *Inoceramus* (highest Turonian or lowest Senonian beds of England)	Turonian.
Glauconitic (Chloritic) sands and sandstones (Cenomanian)	,, *Exogyra columba*	
Grey marls and yellow sandstones . . .	,, *Ostrea carinata*	Cenomanian.
Glauconitic sand	,, *Exogyra conica*	

In the west of Scotland, also, relics of the same type of Cretaceous formations have been preserved under the volcanic plateaux of Mull and Morven. They contain the following subdivisions in descending order :[2]—

White marly and sandy beds with thin seams of lignite	20 feet
Hard white chalk with *Belemnitella mucronata*, &c.	10 ,,
Thick white sandstones with carbonaceous matter	100 ,,
Glauconitic sands and shelly limestones, *Pecten asper*, *Exogyra conica*, *Neithea (Janira) quinquecostata*, *Nautilus deslongchampsianus*, &c. .	60 ,,

That the hard Chalk of Ireland, as well as the Liassic and Rhætic formations below it, once extended to the north-east, at least as far as the basin of the Clyde, has been shown by the remarkable discovery (above alluded to) of large masses of these strata with their characteristic fossils within a great Tertiary volcanic neck in the island of Arran.[3] On the east side of the country large quantities of chalk flints scattered over Aberdeenshire probably indicate that the Chalk lies not far off under the North Sea in continuation of its extension in Denmark. A considerable list of fossils has been obtained from the Aberdeenshire tracts, indicating that they have been derived from more than one horizon in the Cretaceous series. The specimens collected at Moreseat have clearly come from Lower Greensand, Gault, and Upper Greensand strata.[4]

[1] R. Tate, *Q. J. G. S.* xxi. (1865), p. 15 ; Barrois, 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irelande,' Lille, 1876 ; W. F. Hume, *Q. J. G. S.* liii. (1897), p. 540.

[2] Judd, *Q. J. G. S.* xxxiv. p. 736.

[3] See note on p. 1137.

[4] G. Sharman and E. T. Newton, *Geol. Mag.* (1896), p. 247. A. J. Jukes-Browne and J. Milne, *op. cit.* (1898), p. 21.

France and Belgium.—The Cretaceous system so extensively developed in western Europe is distributed in large basins, which, on the whole, correspond with those of the chief rivers. Thus in France there are the basins of the Seine or of Paris, of the Loire or of Touraine, of the Rhone or of Provence, and of the Garonne or of Aquitania, including all the area up to the slopes of the Pyrenees. In most cases, these areas present such lithological and palæontological differences in their Cretaceous rocks as to indicate that they may have been to some extent even in Cretaceous times distinct basins of deposit.

A twofold subdivision of the system is followed in France, but with a difference of nomenclatüre and partly also of arrangement from that in use in England, as shown in the subjoined table :—

[1] From Mons in Belgium, where the deposit is typically developed.

[2] Well seen at Maestricht.

[3] From Champagne.

[4] From Emscher in Westphalia.

[5] From Santonge.

[6] From Cognac.

[7] From Angoulême.

[8] From the basin of the Loire.

[9] From the Charente.

[10] From Rouen (*Rothomagus*).

[11] From the Department of the Aube.

[12] From Apt in Vaucluse.

[13] From Orgon, near Arles.

[14] From Hauterive, on the Lake of Neuchâtel.

[15] From the Château de Valengin, near Neuchâtel.

		Sub-Stages.	N. France and Belgium.	S.-E. and S. France.
Série Supra-crétacée.	Danien.	Montien.[1*]	Calcaire pisolitique. Calcaire de Mons. Tuffeau de Ciply.	Calcaire à *Lychnus* de Rognac. Craie à lignites de Fuveau.
	Danien.	Maestrichtien.[2]	Calcaire à Baculites du Cotentin. Craie de Maestricht.	Calcaires marneux à *Hemipneustes*.
	Senonien.	Campanien.[3]	Craie de Meudon. Craie de Reims.	Calcaires à grands rudistes. Marnes et calc. à *Hippurites dilatatus*.
	Senonien.	Emscherian.[4] Santonien.[5] Coniacian.[6]	Craie à *Marsupites*. Craie à *Micr. cor-anguinum*. Craie à *M. cor-testudinarium*. Craie à *M. brevis*.	Calcaires à hippurites. Grès à échinides. Calcaires à hippurites. Grés à *Micraster brevis*. Couches à *Hippurites Zurcheri*.
	Turonien.	Angoumien.[7]	Craie marneuse à *Micr. breviporus*, et *Tereb. gracilis*.	Calc. à *Hippurites cornuvaccinum* et grès inf. de Mornas. Calc. à *Biradiolites cornupastoris*. Grès d'Uchaux.
	Turonien.	Ligérien.[8]	Craie marneuse à *Inoceramus labiatus*.	Marnes à nucleolites. Calc. à *Amm. nodosoides*.
	Cenomanien.	Carentonien.[9] Rothomagien.[10]	Craie glauconieuse de Normandie. Marnes à *Schlœnbachia rostrata*.	Calc. à *Caprina adversa* et grès de Mondragon. Zone à *Anorthopygus orbicularis*. Zone à *Amm. Mantelli*.
	Albien.[11]	Sables à *Schlœnbachia rostrata*. Calcaire marneux.		Calcaire glauconieux de Clansayes (*Desmoceras inflatum*). Grès et calcaires de Clars.
Série Infra-crétacée.		Jura.		
	Aptien.[12]	Sables à *Acanthoceras milletianum*. Calcaire, &c., à Plicatules.		Marnes de Gargas. Calcaire à *Ancyloceras* et *Ostrea aquila*. Marnes à *Belemnites semicanaliculatus*. Calcaires à *Toucasia*, *Ancyloceras*.
	Urgonien.[13]	Marnes à Orbitolines et Calcaires à Ptérocères et à *Requienia* (*Toucasia*) *Lonsdalei* (Rhodanien). Calcaire à *Requienia ammonia*.		Calcaire à *Requienia* (*Toucasia*) *Lonsdalei*. Calcaire à *Macroscaphites Yvani* et *Crioceras*.
	Neocomien.	Hauterivien.[14]	Calcaire jaune (Neuchâtel). Marnes de Hauterive.	Calcaires à *Crioceras Duvali* et *Belemnites pistilliformis*.
	Neocomien.	Valanginien.[15]	Limonite de Métabief et calcaire roux à *Pygurus rostratus*, *Belemnites pistilliformis*, *B. dilatatus*. Calcaire à *Strombus Sautieri* (*Natica Leviathan*), *Nerinæa gigantea*.	Marnes et Calcaires marneux à Ammonites ferrugineuses.

* For footnotes see previous page.

From this table it will be perceived how marked a lithological difference is traceable between the Cretaceous deposits of the north and south of France. The northern area indeed is linked with that of England, and was evidently a part of the same great basin in which the English Cretaceous rocks were deposited. But in the south, the aspect of the rocks is entirely changed, and with this change there is so marked a difference in the accompanying organic remains as to indicate clearly the separation of the two regions in Cretaceous times.

LOWER CRETACEOUS (INFRA-CRÉTACÉ).—Neocomian.[1]—This division is well seen in the eastern part of the Paris basin. The lowest dark marl, resting irregularly on the top of the Portlandian series, indicates the emersion of these rocks at the close of the Jurassic period, and may represent the Valanginian stage. It is followed by ferruginous sands, calcareous blue marl, spatangus-limestones, and yellow marls (abounding in *Echinospatagus* (*Toxaster*) *complanatus*, *Exogyra Couloni*, *Harpagodes* (*Pterocera*) *pelagi*, *Hoplites radiatus*, &c.), the whole having a thickness of 125 to 140 feet, and representing chiefly the upper or Hauterivian sub-stage. Much more important is the development of the Neocomian deposits in the southern half of France. They present there evidence of deeper water at the time of their formation. The Neuchâtel type (p. 1204) is prolonged into the northern part of Dauphiné, where it is seen in a group of limestones, with *Exogyra Couloni*, &c., in the lower, and *Toxaster complanatus*, &c., in the upper beds. Southwards the limestones are mostly replaced by marls, and the whole at Grenoble reaches a thickness of more than 1600 feet, resting on the upper Jurassic limestones with *Terebratula diphyoides*, and separable into a lower or Valanginian group, with *Harpagodes pelagi*, *Ostrea Couloni*, *O. macroptera*, *Pygurus rostratus*, &c., and an upper or Hauterivian group, with *Hoplites radiatus*, *H. leopoldinus*, *Crioceras Duvali*, *Belemnites dilatatus*, *Rhynchonella peregrina*.

Urgonian.—This name was given by D'Orbigny to a series of massive limestones (1150 feet) developed at Orgon in the lower valley of the Durance, and marked by the presence of *Belemnites latus*, *B. dilatatus*, in the lower part; *Echinospatagus complanatus*, *Exogyra Couloni*, *Neithea* (*Janira*) *atava*, &c., in the central thickest portion; and *Echinospatagus ricordeanus*, *Ancyloceras*, *Crioceras*, &c., in the upper band. The Caprotina limestone of Orgon is a massive white rock, sometimes 1000 feet thick, remarkable for the abundance of its hippuritids, *Requienia ammonia*, *R.* (*Toucasia*) *Lonsdalei*, *R. gryphoides*, gigantic forms of *Nerinæa*, and corals. This type of sedimentation is so local in its occurrence, and is so apt to reappear on different horizons, that some geologists have advocated the abandonment of the term Urgonian and the adoption in its place of "Barremien," from Barrême in the Basses Alpes, where a group of strata above the Hauterivian stage is well developed, and contains a distinct pelagic fauna, which, however, is not found in the north of Europe. At Barrême the group consists of lower white marly limestones, and an upper grey marly limestone, with *Macroscaphites Ivani*, *Desmoceras difficile*, *Lytoceras Phestus*, *Phylloceras infundibulum*. The more argillaceous and sandy type of sediment, which is shown in England by the Atherfield Clay and its equivalents, extends into the northern Cretaceous basin of France, where it appears in a series of sands and clays which in Haute Marne are from 60 to 80 feet thick, and contain *Echinospatagus* (*Toxaster*) *ricordeanus*, *Ostrea Leymeriei*, &c.[2]

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[1] See D'Archiac, *Mém. Soc. Géol. France*, 2e sér. ii. p. 1. Raulin, *op. cit.* p. 219. Ebray, *Bull. Soc. Géol. France*, 2e sér. xvi. p. 213; xix. p. 184. Cornuel, *Bull. Soc. Géol. France*, 2e sér. xvii. p. 742; 3e sér. ii. p. 371. Hébert, *op. cit.* 2e sér. xxiv. p. 323; xxviii. p. 137; xxix. p. 394. Coquand, *op. cit.* xxiii. p. 561. Rouville, *op. cit.* xxix. p. 723. Bleicher, *op. cit.* 3e sér. ii. p. 21. Toucas, *op. cit.* iv. p. 315. Kilian, *op. cit.* xxiii.

[2] Professor De Lapparent ("Traité," 4th edit. p. 1313), brackets the "Punfield Beds" and the Atherfield Clay as the English equivalents of the Barremian stage; but, as already pointed out (*ante*, p. 1185), the "Punfield Beds" have no existence, apart from the general mass of the Lower Greensand to which they belong.

Aptian.—In the typical district round Apt in Vaucluse, this stage consists of a lower group of blue marls (Marnes de Gargas), with *Plicatula placunea*, *Hoplites Dufrenoyi*, *Placenticeras Nisus*, *Ostrea aquila*, *Belemnites semicanaliculatus*, followed by yellowish marly limestone with *Ancyloceras renauxianum* and *Ostrea aquila*. The stage swells out in the Bedoule to a thickness of nearly 1800 feet, consisting of marly limestones and marls in which uncoiled ammonites like *Ancyloceras* are specially conspicuous. Among the more prominent fossils in the lower part are species of *Plicatula* with *Ancyloceras Matheroni* and *Hoplites fissicostatus*; in the upper part come *Belemnites semicanaliculatus*, *Douvilleiceras cornuelianum*, *Placenticeras Nisus*, *Hoplites Dufrenoyi*, &c. In northern France the Aptian stage is chiefly clay, with *Plicatula placunea*, *P. radiola*, hence the name "Argile à Plicatules." Near St. Dizier, Haute Marne, the lower beds are likewise characterised by *Terebratula sella*, *Ostrea aquila*; the middle by *Douvilleiceras cornuelianum*, *Ancyloceras Matheroni*; the upper by *Placenticeras Nisus*, *Hoplites Deshayesi*.

The English type of strata from the Weald upwards is prolonged into France. Fresh-water sands and clays (with *Unio* and *Cyrena*), found above the Jurassic series in the Boulonnais, evidently represent the Weald, and are covered by dark green clays and sands, which are doubtless a continuation of the Folkestone beds, and by a thin blue clay which represents the Gault. Again, in the Pays de Bray, to the west of Beauvais, certain sands and clays resting on the Portlandian strata represent the Wealden series, and are followed by others which may be paralleled with the Urgonian, Albian, and Gault.[1]

In Belgium the Cretaceous system is underlain by certain clays, sands, and other deposits belonging to a continental period of older date than the submergence of that region beneath the sea in which were deposited the uppermost Neocomian beds. These scattered continental deposits were grouped under the name of "Aachenian,"[2] for which is now substituted "Bernissartian." That at least some part of them belongs to older Neocomian time, and may be coeval with the Weald, may be inferred from the remarkable discovery at Bernissart, already alluded to, where, in a buried system of Cretaceous ravines, remains of the terrestrial and fluviatile life of the time have been well preserved (*ante*, p. 1175). The deposit in which these remains have been found consists of fluviatile sands and clays lying under the Chalk, which has been pierced in order to reach the Coal-measures below. The fossils include the complete skeletons of more than twenty individuals belonging to at least two species of *Iguanodon*, together with numerous turtles and fluviatile fishes (*Lepidotus*, *Ophiopsis*). The plants include a number of ferns (*Sagenopteris Mantelli*, *Matonidium Gœpperti*, *Laccopteris Dunkeri*, *Onychiopsis Mantelli*, *Ruffordia Gœpperti*, *Weichselia Mantelli*, *Sphenopteris*, *Cladophlebis*), and some conifers (*Pinites*, *Conites*).[3]

Upper Cretaceous (Série Supra-crétacée).—The Upper Cretaceous rocks of France have been the subject of prolonged and detailed study by the geologists of that country.[4] The northern tracts form part of the Anglo-Parisian basin, in which the

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[1] Wealden deposits have been described as occurring even as far south as the province of Santander, Spain. A. Gonzalerz de Linares, *Anal. Soc. Esp. Hist. Nat.* vii. (1878), p. 487.

[2] On the Aachenian deposits see Dumont, 'Terrains Crétacés et Tertiaires' (edited by M. Mourlon, 1878), i. pp. 11-52. Mr. Purves of the Belgian Geological Survey proposed to substitute Bernissartian for Aachenian to distinguish the Belgian deposits from the very distinct and later type seen at Aix-la-Chapelle, *Bull. Mus. Roy. Nat. Hist. Belg.* ii. (1883), p. 153. See also E. Van den Broeck, *Bull. Soc. Belg. Géol.* xiv. (1900), p. 46.

[3] E. Dupont, *Bull. Acad. R. Belg.* xlvi. (1878), p. 387; L. Dollo, *Bull. Mus. Roy. Hist. Nat.* Brussels, ii. (1883), p. 303; A. C. Seward, *Mem. Mus. R. Hist. Nat.* Brussels, i. (1900).

[4] Notably by MM. Hébert, Toucas, Coquand, and Cornuel. As already stated, considerable differences exist among French and Swiss geologists as to the nomenclature and the lines

Upper Cretaceous rocks of Belgium and England were laid down. The same palæontological characters, and even in great measure the same lithological composition, prevail over the whole of that wide area, which belongs to the northern Cretaceous province of Europe. Apparently only during the early part of the Cenomanian period, that of the Rouen Chalk, did the Anglo-Parisian basin communicate with the wider waters to the south, which were bays or gulfs freely opening to the Atlantic. In these tracts a notably distinct type of Cretaceous deposits was accumulated, which, being that of the main ocean, covers a much larger geographical area and contains a much more widely diffused fauna than are presented by the more limited and isolated northern basin. There are few more striking contrasts between contemporaneously formed rocks in adjacent areas of deposit than that which meets the eye of the traveller who crosses from the basin of the Seine to those of the Loire and Garonne. In the north of France and Belgium, soft white chalk covers wide tracts, presenting the same lithological and scenic characters as in England. In the centre and south of France, the soft chalk is replaced by hard, craggy limestone, with comparatively few sandy or clayey beds. This mass of limestone attains its greatest development in the southern part of the department of the Dordogne, where it is said to be about 800 feet thick. The lithological differences, however, are not greater than those of the fossils. In the north of France, Belgium, and England, the singular molluscan family of the Rudistæ (Hippuritidæ and Radiolitidæ) appears only occasionally and sporadically in the Cretaceous rocks, as if a stray individual had from time to time found its way into the region, but without being able to establish a colony there. In the south of France, however, the hippurites occur in prodigious quantity, often mainly composing the limestones, hence called hippurite limestone (Rudisten-Kalk). They attained a great size, and seem to have grown on extensive banks, like our modern oyster. They appear in successive species on the different stages of the Cretaceous system, and can be used for marking palæontological horizons, as the cephalopods are employed elsewhere. But while these lamellibranchs played so important a part throughout the Cretaceous period in the south of France, the numerous ammonites and belemnites, so characteristic of the Chalk in the Anglo-Parisian basin, were comparatively rare there. The very distinctive type of hippurite limestone has so much wider an extension than the northern or Chalk type of the upper Cretaceous system that it should be regarded as really the normal development. It ranges through the Alps into Dalmatia, and round the great Mediterranean basin far into Asia.

Albian.[1]—The thin blue clay above alluded to as representing the English Gault in the Boulonnais contains such representative fossils as *Douvilleiceras mammillatum*, *Hoplites interruptus*, *Schlœnbachia rostrata*, *Inoceramus sulcatus*, and *Nucula bivirgata*. The same sedimentary facies can be followed into the Paris basin, where the Albian stage consists of a lower green pyritous sandy member (Sables verts), 30 feet thick, covered by an upper argillaceous band which represents the English Gault. These deposits continue the English type round the northern and eastern margin of that basin. They have been found in deep wells around Paris. In the valley of the Meuse and in the Ardennes

of demarcation between the Upper Cretaceous formations, arising in great part from the varying aspect of the rocks themselves, according to the region in which they are studied. I have followed mainly M. Hébert, whose suggestive memoirs ought to be carefully read by the student. See especially his "Ondulations de la Craie dans le Bassin de Paris," *B. S. G. F.* (2) xxix. (1872), p. 446 ; (3) iii. (1875), p. 512 ; and *Ann. Sci. Géol.* vii. (1876) ; "Description du Bassin d'Uchaux," *Ann. Sci. Géol.* vi. (1875) ; "Terrain Crétacé des Pyrénées," *B. S. G. F.* (2) xxiv. (1867), p. 323 ; (3) ix. (1880), p. 62. The progress of the study of the zonal distribution of fossils has introduced a number of minor subdivisions, and has given much assistance in the correlations of the formations in widely separated districts.

[1] See, besides the works already cited, Barrois, *B. S. G. F.* 2e sér. iii. p. 707 ; *Ann. Soc. Géol. du Nord*, ii. p. 1 ; v. p. 284 ; Renevier, *B. S. G. F.* 2e sér. ii. p. 704.

the stage consists of three subdivisions: (1) a lower green sand (*Douvilleiceras mamillatum*), with phosphatic nodules; (2) a brick clay with *Hoplites lautus, H. tuberculatus;* (3) a porous calcareous and argillaceous sandstone (*Gaize*), containing a large percentage of silica soluble in alkali (*Schlœnbachia rostrata*, &c.).

Cenomanian (Craie glauconieuse).—According to the classification of M. Hébert this stage is composed of two sub-stages: 1st, Lower or Rouen Chalk, equivalent to the Upper Greensand and Grey Chalk of England. In the northern region of France and Belgium this sub-stage consists of the following subdivisions: *a*, a lower assise of glauconitic beds like the English Upper Greensand, containing *Schlœnbachia rostrata* below and *Pecten asper* above ("Rothomagian" sub-stage); *b*, Middle glauconitic chalk with *Turrilites tuberculatus, Holaster carinatus*, &c., probably equivalent to the English Glauconitic Marl and Chalk Marl; *c*, Upper hard, somewhat argillaceous, grey chalk with *Holaster subglobosus;* the threefold subdivision of this assise already given, is well developed in the north of France; *d*, Calcareous marls with *Actinocamax plenus* ("Carentonian" sub-stage). 2nd, Upper or marine sandstone; according to M. Hébert this sub-stage is wanting in the northern region of France, England, and Belgium. In the old province of Maine it consists of sands and marls with *Anorthopygus orbicularis, Ostrea columba, Trigonia crenulata, Acanthoceras rothomagense*, &c. Farther south these strata are replaced by limestones with hippurites (*Caprina adversa*), which extend up into the Pyrenees and eastwards across the Rhone into Provence.[1] Around Marseilles the stage has at its base a coarse sandstone (*Acanthoceras Mantelli, Pecten asper, Holaster subglobosus, Orbitolina concava*). Higher up come the hippurite limestones, with *Caprina adversa*, and in their middle a zone of marls and lignites.

Turonian (Craie marneuse).[2]—This stage presents a very different facies according to the part of the country where it is examined. In the northern basin, according to M. Hébert, only its lower portions occur, separated by a notable hiatus from the base of the Senonian stage, and consisting of marly chalk with *Inoceramus labiatus, I. Brongniarti, Rhynchonella Cuvieri, Mammites nodosoides, M. rusticus, Pachydiscus peramplus, Terebratulina gracilis* ("Ligerian" sub-stage). He placed the zone of *Holaster planus* at the base of the Senonian stage, and believed that in the hiatus between it and the Turonian beds below, the greater part of the Turonian stage is really wanting in the north. On the other hand, Dr. Barrois and others would rather regard the zone of *Holaster planus* as the top of the Turonian stage ("Angoumian" sub-stage). In the north of France, as in England, it is a division of the White Chalk, containing *Pachydiscus peramplus, Scaphites Geinitzii, Spondylus spinosus, Inoceramus inæquivalvis, Terebratula semiglobosa, Holaster planus, Ventriculites moniliferus*, &c. Strata with *Inoceramus labiatus*, marking the base of the Turonian stage, can be traced through the south and south-east of France into Switzerland. These in Provence consist of marls with *Mammites nodosoides*, which are covered by marls, sandstones, and massive limestones with *Ostrea columba* and enormous numbers of hippurites (*Hippurites cornuvaccinum, Biradiolites cornu-pastoris*, &c.). These hippurite limestones sweep across the centre of Europe and along both sides of the great Mediterranean basin into Asia, forming one of the most distinctive landmarks for the Cretaceous system. A distinguishing feature of the stage at the Etang de Berre is the presence in it of a laminated clay containing leaves of dicotyledonous plants (*Myrica, Magnolia, Salix*), together with cycads and conifers.

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[1] See the memoir on the Upper Cretaceous Rocks of the basin of Uchaux (Provence) by Hébert and Toucas, *Ann. Sciences Géol.* vi. (1875).

[2] For a review and parallelism of the Turonian, Senonian, and Danian stages in the north and south of Europe see Toucas, *B. S. G. F.* 3me sér. x. (1882) p. 154; xi. p. 344; xix. p. 506; for a general description of the formations in the south-east of France, see Fallot, *Ann. Sci. Géol.* xviii. 1, 1885, and *B. S. G. F.* (3) xiv. (1886), p. 1. The memoir of M. Grossouvre cited on p. 1181 should be consulted for the Upper Cretaceous formations.

Senonian.—This stage is most fully developed in the northern basin, where it consists mainly of White Chalk in two divisions: 1st, Lower (Emscherian), separable into two sub-stages, in the lower of which (Coniacian)*Micraster cor-testudinarium*, and in the upper (Santonian) *M. cor-anguinum* is the prevalent urchin. The same palæontological facies occurs in these as in the corresponding strata of England. 2nd, Upper (Campanian), Belemnitella sub-stage, formed of the Reims Chalk below with *Actinocamax quadratus*, *Micraster fastigatus*, *M. glyptus*, and the Chalk of Compiegne and Meudon above, with *Belemnitella mucronata*, *Magas pumilus*, *Micraster Brongniarti*, *Ostrea vesicularis*. In the south and south-east of France the corresponding beds consist of limestones, sandstones, and marls, with abundant hippurites, and also include some fresh-water deposits and beds of lignite.

Reference may here be made to the marked abundance of phosphate of lime in some parts of the chalk in northern France and Belgium. The white calcareous chalk occasionally becomes grey in colour from the abundant grains of phosphate of lime dispersed through it. This structure is particularly developed in Picardy at the base of the zone of *Actinocamax quadratus*, and especially at the bottom of synclinal folds of the strata. It is local and lenticular in its occurrence, but it has given rise to an active industry.[1]

Danian.—This subdivision of the Cretaceous system is specially developed in the northern basin. In the neighbourhood of Paris and in the department of Oise and Marne, a rock long known as the "Pisolitic Limestone" occurs in patches, lying unconformably on the different parts of the Chalk. It has been ascertained, however, that these outliers are not all of the same age, and that some of them belong to the very latest parts of the Cretaceous series, or form passage-beds into the Tertiary formations.[2] The long interval which must have elapsed between the deposition of the highest Senonian beds and these limestones is indicated not only by the evidence of great erosion of the Chalk, but also by the marked palæontological break between the two rocks. The general aspect of the fossils resembles that of the older Tertiary formations, but among them are some undoubted Cretaceous species. In what are regarded as the oldest of these deposits (Montereau and the Bois d'Esmans) they consist of hard, somewhat coarse-grained limestones with *Neithea quadricostata* and *Nautilus hebertinus*. The rest of them, grouped in the latest (Montian) sub-stage of the Cretaceous system, have a lower division of concretionary limestones, mainly built up of calcareous algæ (*Lithothamnium*) with *Pleurotomaria penultima* and large forms of *Cerithium*, *Neithea quadricostata*, *Lima tecta*, *Nautilus danicus*, associated with a number of later types found also in the upper division. This latter portion of the series comprises the Calcaire de Meudon (6 or 7 feet), surmounted by marls that have been formed by the decay of the limestone. This calcareous band is mainly formed of foraminifera, echinids (*Cidaris Tombecki*, *Goniopygus minor*) with some calcareous algæ, large *Cerithium*, *Turitella montensis*, *Pseudoliva robusta*, *Mitra Dewalquei*. Remnants of a fresh-water formation are found at the top, shown by the occurrence of *Viviparus*, *Physa*, and other lacustrine shells.

In the south-east of Belgium the Danian stage is well exposed, resting unconformably on a denuded surface of chalk. In Hainault, it consists of successive bands of yellowish or greyish chalk, between some of which there are surfaces of denudation, with perforations of boring mollusks, so that it contains the records of a prolonged period (Tuffeau de Ciply, Calcaire de Mons). The Tuffeau de Ciply lies on the phosphatic White Chalk with flints forming the top of the Senonian stage. It is a pale limestone, which in the lower part (*Tuffeau de St. Symphorien*) contains an obviously Cretaceous fauna, including *Belemnitella mucronata*, *Baculites Faujasi*, *Neithea quadricostata*, *Terebratula carnea*,

[1] J. Gosselet, *Ann. Soc. Géol. Nord.* xx. (1893), p. 371; xxi. p. 2; xxiv. pp. 109, 119; xxix. p. 65. M. de Mercy, *B. S. G. F.* 3me sér. xv. p. 719. J. Cornet, *Ann. Soc. Géol. Belge.* xxvii. (1900).

[2] Meunier Chalmas, *B. S. G. F.* 3e sér. xxv. p. 82.

Crania ignabergensis. The upper part, though like the lower in lithological character, contains a remarkably different fauna, consisting largely of gasteropods like those of the Mons limestone, while bryozoa abound in certain layers associated with echinids and brachiopods of Cretaceous species. The Calcaire de Mons, which reaches a thickness of about 300 feet under the town whence it takes its name, lies on the White Chalk, and is immediately overlain by the Tertiary formations. It is a coarse, yellowish limestone composed of foraminifera, calcareous algæ, and other organisms, which have a strikingly Tertiary aspect, since they include species of *Triton, Fusus,* and *Pseudoliva,* together with fresh-water or terrestrial forms, such as *Pupa, Physa,* and *Bithinia.*[1]

Another well-known representative of the highest Cretaceous deposits in the Franco-Belgian area is the chalk or tuffeau of Maestricht. As at Ciply and Mons, it is separated from the Senonian chalk below by a gravelly layer indicating considerable previous erosion of the older formation. It has yielded a remarkably abundant fauna, including many familiar upper Cretaceous species—*Belemnitella mucronata, Baculites Faujasi, B. anceps, Nautilus Dekayi, Scaphites constrictus, Ostrea vesicularis, Crania ignabergensis, Trigonosemus* (*Fissurirostra*) *Palissii* (characteristic), *Hemipneustes striato-radiatus, Cidaris Faujasi,* numerous bryozoa (*Eschara* and other genera), some hippurites (*Hippurites Lapeirousei, Sphærulites Hœninghausi*), fishes (*Acrodus, Corax, Enchodus, Otodus, Pycnodus*), and the remains of the last of the great Cretaceous mosasaurs.

The later members of the Cretaceous system, representing perhaps the period of the Maestricht Chalk, emerge from under the Tertiary formations of the vast Aquitanian plain. In the departments of the Charentes the so-called "Dordonian" sub-stage, which is paralleled with the Maestrichtian, is well developed in a mass of limestones about 250 feet thick, containing numerous hippurites together with *Hemiaster prunella, Ostrea larva, O. acutirostris, Sphenodiscus, Pachydiscus, Scaphites.* At the top of these marine beds lies a group of sandstones about 50 feet thick, which show traces of the advent of fresh water. The evidence of this important geographical change becomes still further marked to the south-east in Provence, where there is striking proof of a gradual shallowing of the Upper Cretaceous sea, until that area had become a fluviatile or lacustrine tract, in which during the later stages of the period a mass of fresh-water strata more than 2600 feet thick was accumulated. This enormous development of sediments consists of limestones, marls, and lignites grouped in the following subdivisions: (*a*) Lower limestones with *Bulimus proboscideus* and *Cyclophorus Heberti;* (*b*) beds with lignite which at Fuveau are more than 1200 feet thick; (*c*) limestones with *Lychnus, Physa, Cyclophorus, Anostomopsis;* (*d*) reptiliferous sandstones and limestones with *Lychnus, Physa,* &c. The second group of strata (*b*) shows a remarkably thick accumulation of fluvio-lacustrine deposits with numerous seams of lignite or coal (some of them 5 feet thick), bones of crocodiles, and numerous fresh-water or estuarine shells (*Cerithium, Melania, Melanopsis, Unio, Cyrena*).[2]

Germany.—The Cretaceous deposits of Germany, Denmark, and the south of Sweden were accumulated in the same northern province with those of Britain, the north of France, and Belgium, for they present on the whole the same palæontological succession, and even to a considerable extent the same lithological characters. It would appear that the western part of this region began to subside before the eastern, and attained a greater amount of depression beneath the sea. In proof of this statement, it may be mentioned that the Neocomian clays of the north of England extend as far as the Teutoburger Wald, but are absent from the base of the Cretaceous system in Saxony and Bohemia. In north-west Germany, Neocomian strata, under the name of Hils, appear at many points between the Isle of Heligoland (where representatives of part of the Speeton Clay and the Hunstanton Red Chalk occur) and the east of Brunswick,

[1] MM. Rutot and Van den Broeck, *Ann. Soc. Géol. Belge.* xii. xiii.; Cornet and Briart, *B. S. G. F.* 3me sér. ii.

[2] Matheron, *B. S. G. F.* 2me sér. xxi.; 3me sér. iv.; Collot, *op. cit.* xix.

indicative of what was, doubtless, originally a continuous deposit. In Hanover, they consist of a lower series of conglomerates (Hils-conglomerat), and an upper group of clays (Hils-thon). Appearing on the flanks of the hills which rise out of the great drift-covered plains, they attain their completest development in Brunswick, where they attain a total thickness of 450 feet, and consist of a lower group of limestone and sandy marls, with *Echinospatagus* (*Toxaster*) *complanatus*, *Exogyra Couloni* (*sinuata*), *Polyptichites bidichotomus*, *Olcostephanus* (*Astieria*) *astierianus*, and many other fossils; a middle group of dark blue clays with *Belemnites brunsvicensis*, *Placenticeras Nisus*, *Crioceras* (*Ancyloceras*) *Emerici*, *Exogyra Couloni* (*sinuata*), &c., and an upper group of dark and whitish marly clays with *Douvilleiceras Martini*, *Hoplites Deshayesi*, *Placenticeras Nisus*, *Belemnites Ewaldi*, *Toxoceras ? royerianum*, *Crioceras*, &c.[1] Below the Hils-thon in Westphalia, the Harz, and Hanover, the lower parts of the true marine Neocomian series are replaced by a massive fluviatile formation corresponding to the English Wealden, and divisible into two groups: 1st, Deister sandstone (150 feet), like the Hastings Sand of England, consisting of fine light yellow or grey sandstone (forming a good building material), dark shales, and seams of coal varying from mere partings up to workable seams of three, and even more than six, feet in thickness. These strata are full of remains of terrestrial vegetation (*Equisetum*, *Baiera*, *Oleandridium Laccopteris*, *Sagenopteris*, *Anomozamites*, *Pterophyllum*, *Podozamites*, and a few conifers), also shells of fresh-water genera (*Cyrena*, *Viviparus*), cyprids, and remains of *Lepidotus* and other fishes; 2nd, Weald Clay (65-100 feet) with thin layers of sandy limestone (*Cyrena*, *Unio*, *Viviparus*, *Melania*, *Cypris*, &c.).[2] The Gault (Aptian and Albian) of north-western Germany contains three groups of strata. The lowest of these consists of pale clays and marls (Gargas-Mergel) with *Belemnites Ewaldi*, *Douvilleiceras Martini*, *Hoplites Deshayesi*. The middle (zone of *Belemnites Strombecki*) consists of a lower clay with *Acanthoceras milletianum* and an upper clay with *Hoplites tardefurcatus*. The highest contains at its base a clay with *Belemnites minimus*, and at its top the widely diffused and characteristic "Flammenmergel"—a pale clay with dark flame-like streaks, containing the zone of *Schlœnbachia rostrata*, *Hoplites lautus*, &c.[3] In the Teutoburger Wald the Gault becomes a sandstone.

The Upper Cretaceous rocks of Germany present the greatest lithological contrasts to those of France and England, yet they contain so large a proportion of the same fossils as to show that they belong to the same period, and the same area of deposit.[4] The Cenomanian stage (=Unterer Pläner) consists in Hanover of earthy limestones and

[1] A. von Strombeck, *Z. D. G. G.* i. p. 462; xii. p. 20; *N. Jahrb.* 1855, pp. 159, 644; Judd, *Q. J. G. S.* xxvi. p. 343; Vacek, *Jahrb. Geol. Reichsanst.* 1880, p. 493.

[2] W. Dunker, 'Ueber den norddeutsch. Wälderthon, u. s. w.,' Cassel, 1844; Dunker and Von Meyer, 'Monographie der norddeutsch. Wälderbildung, u. s. w.,' Brunswick, 1846; Heinrich Credner, 'Ueber die Gliederung der oberen Jura und der Wealdenbildung in nordwestlichen Deutschland,' Prague, 1863; C. Struckmann, 'Die Wealden-Bildungen der Umgegend von Hannover,' 1880; A. Schenk on the Wealden Flora of North Germany, *Palæontographica*, xix. xxiii.; Gugel, *Jahrb. Preuss. Geol. Landesanst.* xiv. (1893), p. 158. A. Hosius has described the intercalation of marine beds containing *Ostrea*, *Nucula*, *Cucullæa*, and *Rhizocorallium* in the Westphalian Wealden series, *Z. D. G. G.* xlv. (1893), pp. 34-54. A. von Koenen has recently grouped the north German Lower Cretaceous series in accordance with the classification adopted for the formations on the north side of the Alps. *Nachr. Ges. Wiss. Göttingen*, 1901, 1902.

[3] *Geol. Mag.* vi. (1869), p. 261. A. von Strombeck, *Z. D. G. G.* xlii. (1890), p. 557.

[4] On the distribution of the Cephalopods in the Upper Cretaceous rocks of north Germany, see C. Schlüter, *Z. D. G. G.* xxviii. p. 457, where the formations are grouped in palæontological zones (*Geol. Mag.* 1877, p. 169), and *Palæontographica*, xxiv. pp. 123-263, 1876. For the *Inocerami*, *Z. D. G. G.* xxxix. p. 735; Echinids, *ante*, p. 1168. For the lithological facies of the Saxon Cretaceous formations, see W. Petrascheck, *Isis*, Dresden, 1899, Heft. ii.

marls (Pläner), which traced southward are replaced in Saxony and Bohemia by glauconitic sandstones (Unter-Quader) and limestone (Unter-Plänerkalk). The lowest parts of the formation in the Saxon, Bohemian, and Moravian areas are marked by the occurrence in them of clays, shales, and even thin seams of coal (Pflanzen-Quader), containing abundant remains of a terrestrial vegetation which possesses great interest, as it contains the oldest known European forms of hard-wood trees (willow, ash, elm, laurel, &c.). The Turonian beds, traced eastwards, from their chalky and marly condition in the Anglo-Parisian Cretaceous basin, change in character, until in Saxony and Bohemia they consist of massive sandstones (Mittel-Quader) with limestones and marls (Mittel-Pläner). In these strata, the occurrence of such fossils as *Inoceramus labiatus, I. Brongniarti, Pachydiscus peramplus, Scaphites Geinitzii, Spondylus spinosus, Terebratula semiglobosa*, &c., shows their relation to the Turonian stage of the west. The Senonian[1] stage presents a yet more extraordinary variation in its eastern prolongation. The soft upper Chalk of England, France, and Belgium, traced into Westphalia, passes into sands, sandstones, and calcareous marls, the sandy strata increasing southwards till they assume the gigantic dimensions which they present in the gorge of the Elbe and throughout the picturesque region known as Saxon Switzerland (Ober-Quader).[2] The horizon of these strata is well shown by such fossils as *Actinocamax quadratus, Belemnitella mucronata, Nautilus danicus, Marsupites testudinarius, Bourgueticrinus ellipticus, Crania ignabergensis*, &c.

At Aix-la-Chapelle an exceedingly interesting development of Upper Cretaceous rocks has been found. These strata, referable to the Senonian stage, consist of a lower group of sands with *Inoceramus lobatus, Actinocamax quadratus*, and abundant remains of terrestrial vegetation (p. 1165),[3] and an upper group of marl and marly chalk with *Belemnitella mucronata, Ostrea vesicularis, Crania ignabergensis, Mosasaurus*, &c.

Switzerland and the Chain of the Alps.[4]—In the Jura, and especially round Neuchâtel, the Neocomian stage is typically developed. Its name and those of its two sub-stages have been taken from localities in that region where they are best seen (p. 1196). (1) Valanginian—a group of limestones and marls (150-400 feet) with *Echinospatagus* (*Toxaster*) *Campichei, Pygurus rostratus, Strombus Sautieri* (*Natica Leviathan*), *Nerinæa gigantea, Cidaris hirsuta, Belemnites pistilliformis, B. dilatatus, Oxynoticeras gevrilianum*, &c.; (2) Hauterivian—a mass of blue marls surmounted by yellowish limestones, the whole having a thickness that varies up to more than 300 feet; *Echinospatagus* (*Toxaster*) *complanatus, Ostrea Couloni, Neithea* (*Janira*) *atava, Perna Mulleti, Nautilus pseudo-*

[1] The Senonian stage of N.W. Germany has recently been more specially studied with reference to its palæontological zones. The Lower Senonian is marked by the abundance of *Actinocamax* (*Belemnitella*), with *A. westfalicus* in the lower part, *A. granulatus* in the middle, and *A. quadratus* at the top. The Upper Senonian is subdivided into two stages, of which the lower is characterised by *Belemnitella mucronata*, while the upper (without *Belemnitella*) is regarded as equivalent to the Danian of Denmark. E. Stolley, *Archiv. Anthrop. Geol. Schleswig-Holst.* 1897, ii. p. 271; G. Müller, *Zeitsch. Prakt. Geol.* 1900, p. 397; *Z. D. G. G.* 1900, p. 38.

[2] G. Maas (*Z. D. G. G.* li. (1899), p. 243) describes the Lower Chalk of the sub-hercynian Quadersandstein.

[3] For a list of these plants see H. von Dechen, 'Geol. Paläont. Übersicht der Rheinprovinz,' &c. 1884, p. 427.

[4] Studer's 'Geologie der Schweiz.' Gümbel, 'Geognostiche Beschreib. Bayer. Alpen,' vol. i. p. 517 *et seq.*; 'Geognostische Beschreib. des Ostbayer. Grenzegebirg.' 1868, p. 697. Jules Marcou, *Mém. Soc. Géol. France* (2), iii. P. de Loriol, 'Invertébrés de l'Étage Néocomien moyen du Mt. Salève,' Geneva, 1861. Renevier, *B. S. G. F.* (3) iii. A. Favre, *ibid.* The Maps and Memoirs in the *Beiträge z. Geol. Karte der Schweitz*, especially the work of Mösch, Baltzer, and Burckhardt. Von Hauer's 'Die Geologie der Oesterr. Ungar. Monarchie, 1878, p. 505 *et seq.* E. Fraas, 'Scenerie der Alpen.'

elegans, Hoplites radiatus, H. leopoldinus, Olcostephanus (*Astieria*) *astierianus, Belemnites pistilliformis, B. dilatatus*, &c. The Aptian and Albian stages (Gault) are recognisable in a thin band of greenish sandstone and marls which have long been known for their numerous fossils (Perte du Rhone, St. Croix).

In the Alpine region, the Neocomian formation is represented by several hundred feet of marls and limestones, which form a conspicuous band in the mountainous range separating Berne from Wallis, and thence into eastern Switzerland and the Austrian Alps (Spatangenkalk). Some of these massive limestones are full of hippurites of the *Caprina* group (Caprotinenkalk, with *Requienia* (*Toucasia*) *Lonsdalei, Radiolites neocomiensis*, &c.), others abound in polyzoa (Bryozoenkalk), others in foraminifera (Orbitolitenkalk). The Aptian and the Albian stages traceable in the Swiss Jura can also be followed into the Alps of Savoy. In the Vorarlberg and Bavarian Alps their place is taken by calcareous glauconite beds and the Turrilite greensand (*T. Bergeri*); but in the eastern Alps they have not been recognised. The lowest portions of the massive *Caprotina* limestone (Schrattenkalk) are believed to be Neocomian, but the higher parts are Upper Cretaceous.

One of the most remarkable formations of the Alpine regions is the enormous mass of sandstone which, under the name of Flysch and Vienna Sandstone, stretches from the south-west of Switzerland through the northern zone of the mountains to the plains of the Danube at Vienna, and thence into the Carpathians.[1] Fossils are exceedingly rare in this rock, the most frequent being fucoids, which afford no clue to the geological age of their enclosing strata. That the older portions in the eastern Alps are Cretaceous, however, is indicated by the occurrence in them of occasional *Inocerami*, and by their interstratification with true Neocomian limestone (Aptychenkalk). The definite subdivisions of the Anglo-Parisian Upper Cretaceous rocks cannot be applied to the structure of the Alps, where the formations are of a massive and usually calcareous nature. In the Vorarlberg, they consist of massive limestones (Seewenkalk) and marls (Seewenmergel), with *Acanthoceras Mantelli, Turrilites costatus, Inoceramus striatus, Holaster carinatus*, &c. In the north-eastern Alps, they present the remarkable facies of the Gosau beds, which consist of a variable and locally developed group of marine marls, sandstones, and limestones, with occasional intercalations of coal-bearing fresh-water beds. These strata rest unconformably on all rocks more ancient than themselves, even on older Cretaceous groups. They have yielded about 500 species of fossils, of which only about 120 are found outside the Alpine region, chiefly in Turonian, partly in Senonian strata. Much discussion and a copious literature has been devoted to the history of these deposits.[2] The loosely imbedded shells suggested a Tertiary age for the strata; but their banks of corals, sheets of orbitolite- and hippurite-limestone and beds of marl with *Ammonites, Inocerami*, and other truly Cretaceous forms, have left no doubt as to their really Upper Cretaceous age. Among their subdivisions, the zone of *Hippurites cornu-vaccinum* is recognisable. They probably represent the upper part of the Turonian and the whole of the Senonian stages. From some lacustrine beds of this age, near Wiener Neustadt, a large collection of reptilian remains has been

[1] See K. M. Paul, "Der Wienerwald: Ein Beitrag zur Kenntniss der nordalpinen Flyschbildungen," *Jahrb. k. k. Geol. Reichst.* 1898, pp. 53-178.

[2] See among other memoirs, Sedgwick and Murchison, *Trans. Geol. Soc.* 2nd ser. iii. Reuss, *Denkschrift. Akad. Wien*, vii. 1; *Sitzb. Akad. Wien*, xi. 882. Stoliczka, *Sitzb. Akad. Wien*, xxviii. 482; lii. 1. Zekeli, *Abhandl. Geol. Reichsanst. Wien*, i. 1 (Gasteropods). F. von Hauer, *Sitzb. Akad. Wien*, liii. 390 (Cephalopods); 'Palæont. Oesterreich,' i. 7; 'Geologie,' p. 516. Zittel, *Denkschrift. Akad. Wien*, xxiv. 105; xxv. 77 (Bivalves). Bünzel, *Abhandl. Geol. Reichsanst.* v. 1. Gümbel, 'Geognostische Beschreib. Bayerisch. Alpen,' 1861, p. 517 *et seq.* Redtenbacher, *Abhandl. Geol. Reichsanst.* v. (Cephalopods). Tausch, *Verhandl. k. k. Geol. Reichsanst.* 1886, p. 180. H. Kynaston, *Q. J. G. S.* l. (1894), p. 120.

obtained, including deinosaurs, chelonians, a crocodile, a lizard, and a pterodactyle in all fourteen genera and eighteen species.[1] Probably more or less equivalent to the Gosau beds are the massive hippurite-limestones and certain marls, containing *Belemnitella mucronata*, *Echinocorys vulgaris*, &c., of the Salzkammergut and Bavarian Alps.[2] The Upper Cretaceous rocks of the south-eastern Alps are distinguished by their hippurite-limestones (Rudistenkalk) with shells of the *Hippurites* and *Radiolites* groups, while the Lower Cretaceous limestones are marked by those of the *Caprina* group. They form ranges of bare white, rocky, treeless mountains, perforated with tunnels and passages (Dolinen, p. 477). In the southern Alps white and reddish limestones (Scaglia) have a wide extension.

Basin of the Mediterranean.—The southern type of the Cretaceous system attains a great development on both sides of the Mediterranean basin. The hippurite (*Caprotina*) limestones of Southern France and the Alps are prolonged through Italy into Greece, whence they range into Asia Minor and into Asia. Cretaceous formations of the same type appear likewise in Portugal, Spain, and Sicily, and cover a vast area in the north of Africa. The Portuguese representation of the system at the extreme west of the region presents some interesting features, especially in the evidence for the alternation of marine and estuarine or fluviatile deposits during Cretaceous time, and in the light which it casts on the Cretaceous flora. The marine strata are there sufficiently well developed to enable them to be paralleled with the successive formations of central and northern Europe. In the region of Lisbon and Bellas, from the base of the Neocomian series upwards, successive horizons of plant-bearing strata are met with in a series of strata with distinctively marine fossils. Thus *Cyclopteris tenuistriata* is found at the very base of the series and terrestrial plants (of which eighty-eight species are known), continue throughout the Valanginian sub-stage but with intercalations of marine shells. In Hauterivian time the sea had established itself over the area, as is shown by a mass of limestones and marls, 50 to 150 feet thick, with *Ostrea Couloni*, *Neithea* (*Janira*) *atava*, *Olcostephanus* (*Astieria*) *astierianus*. The Urgonian stage is marine in the lower part, but passes up into the sandstone series of Almargem, which abound in remains of terrestrial vegetation, but include a marine band in their centre which appears to mark the Aptian part of the Lower Cretaceous series. This flora among its abundant ferns, cycads, and conifers includes some primitive types of angiosperms (*Protorhipis*, *Changarniera*, *Yuccites*, *Delgadopsis*, *Eolirion*). The equivalents of the Albian and possibly the lower part of the Cenomanian group (Bellasian of Choffat) are again marked by the alternation of marine bands among others full of land-plants. Towards the base of this stage *Placenticeras Uhligi* and *Schloenbachia inflata* (*rostrata*) are found, while higher up come *Polyconites Verneuli*, *Horiopleura Lamberti*, and *Exogyra pseudo-africana*. The flora shows an increasingly modern aspect by the appearance of 47 species of dicotyledons, some of which belong to genera familiar among the living plants of to-day (*Sassafras*, *Eucalyptus*, *Laurus*, *Myrica*).[3] The lower part of the Portuguese Cenomanian strata consists of sandstones, still charged with terrestrial plants. These are succeeded by limestones with marine shells and other fossils (*Ostrea flabellata*, *Exogyra pseudo-africana*, *Horiopleura Lamberti*, *Neolobites*, *Alveolina*, *Douvilleiceras naviculare*). The Turonian stage is fully represented at the mouth of the Mondego, where it consists of a series of thoroughly marine limestones (*Mammites Rochebrunei*, *Inoceramus labiatus*, *Pachydiscus*, *Actæonella*, &c.). The Portuguese Senonian series, again, presents two distinct facies. In the more westerly region the strata consist of

[1] Seeley, *Q. J. G. S.* 1881, p. 620.

[2] Gümbel gives a table of correlations for the European Cretaceous rocks with those of Bavaria, 'Geognost. Beschreib. Ostbayer. Grenzgeb.' pp. 700, 701.

[3] On the Lower Cretaceous flora of Portugal see De Saporta, *Compt. rend.* cvi. (1888), p. 1500; cxi. (1890) and cxiii. (1891). W. M. Fontaine, *Monograph* xv. *U.S. G. S.* L. F. Ward, 16*th Ann. Rep. U.S. G. S.* (1896), p. 510.

sandstones, which are quite marine. The presence in them of *Hoplites Marroti* indicates that they belong to the highest part of the Cretaceous system, though unfortunately their relations to the Turonian series cannot be seen. Neither has any representative of them been found in the fluvio-marine group which elsewhere appears to represent part at least of the Senonian stage. This group of green and red marls and fine sandstones contains fresh-water or estuarine shells (*Cyrena*, *Hydrobia*, *Mytilus*), a rich flora including dicotyledons, a number of fishes (*Clupea*, *Teleosteus*) with *Megalosaurus*, *Crocodilus*, and *Chelone*.[1]

On the southern side of the Mediterranean basin the Cretaceous system spreads over wide tracts of Northern Africa. In the desert region south of Algiers, where it extends in broad plateaux with sinuous lines of terraced escarpment,[2] the various subdivisions from the Neocomian up through the other Lower Cretaceous formations into the upper part of the system have been recognised, perhaps including even the Danian stage. An important member of the system forms the upper part of the "Nubian Sandstone" which plays so important a part in the scenery of north-eastern Africa. This formation extends into Syria and is found in the Lebanos, where it attains a thickness of sometimes 1600 feet, and has been regarded as probably of Albian age.[3] Higher up come the shales, probably Turonian, from which, in that region, so large an assemblage of fossil fishes has been obtained.

Russia.—The Cretaceous formations, which are well developed in the range of the Carpathian mountains, sink below the Tertiary deposits in the plains of the Dniester, and rise again over a vast region drained by the Donetz and the Don. They have been studied in central and eastern Russia by the officers of the Russian Geological Survey, who have pointed out the remarkable resemblance between their organic remains and those of the Anglo-French region. There is in particular a close parallelism between them and the English Speeton Clay in their intimate relationship to the Jurassic system below. The Volgian group already (p. 1157) referred to is succeeded by typical Neocomian deposits, which are well developed in the district of Simbirsk along the Volga, where they consist of dark clays with sandy layers and phosphatic concretions, divisible into three horizons. The lowest of these yields pyritous ammonites, especially *Olcostephanus versicolor*, *O. inversus*, also *Belemnites pseudo-panderianus*, *Astarte porrecta*. The middle zone contains septaria enclosing *Olcostephanus* (*Simbirskites*) *Decheni*, *umbonatus*, *progrediens*, *fasciatofalcatus*, *discofalcatus*, *Barboti*, *Inoceramus aucella*, *Rhynchonella obliterata*. The highest zone is almost unfossiliferous near Simbirsk, but its lower layers yield *Pecten crassitesta*. Deposits of the same type as the Anglo-French Aptian are well developed in the governments of Simbirsk and Saratov, and are characterised by *Hoplites Deshayesi* and *Amaltheus bicurvatus*. The Albian or Gault, which is found in the government of Moscow, and may eventually be traced over a wide area, has yielded a number of ammonites, especially of the genus *Hoplites* (*H. dentatus*, *talitzianus*, *Bennettiæ*, *Engersi*, *Tethydis*, *jachromensis*, *Dutemplei*, *Desmoceras Beudanti*). This stage is well developed in the Caucasus, Transcaucasia, and the trans-Caspian region. In the chief Russian Cretaceous area the Cenomanian stage begins with dark clay closely related to the underlying Jurassic series, from the denudation and rearrangement of which it may have been derived. The clay shades upward into sandy, glauconitic, and phosphatic deposits, which gradually assume the

[1] P. Choffat, *Communic. Commission. Trabal. Geol. Portugal*, ii. Fasc. ii.; 'Receuil de Monographies Stratigraphiques sur le système Crétacé,' Service. Geol. Portugal, Part ii. 1900, and 'La Faune Crétacique du Portugal,' vol. i. parts i.-iv. 1902.

[2] Coquand, 'Description géol. et paléontol. de la région sud de la province de Constantin,' 1862; Rolland, *B. S. G. F.* (3) ix. p. 508; Peron, *op. cit.* p. 436; this author has published a valuable memoir on the Geology of Algeria, with a full bibliography, *Ann. Sciences Géol.* 1883; Zittel, 'Beiträge zur Geologie der Libyschen Wüste,' 1883.

[3] Diener, *Z. D. G. G.* xxxix. p. 314.

condition of chalky marls. These Cenomanian strata appear to have a wide extent at the base of the Upper Cretaceous formations of Central Russia. They contain numerous remains of fishes (*Ptychodus, Lamna, Odontaspis, Otodus*) with bones of ichthyosaurs and plesiosaurs. Ammonites are rare, but *Schlœnbachia varians* occurs, also *Actinocamax plenus, Exogyra haliotidea, E. conica, Ostrea hippopodium, Neithea* (*Janira*) *quinquecostata, Pecten laminosus, Rhynchonella nuciformis*, &c. Turonian strata have likewise been found over a wide tract in Central Russia. The lower bands with *Inoceramus* (*I. russiensis, labiatus, Brongniarti, lobatus* aff.) abundant *Belemnitella* and *Ostrea vesicularis* are of constant occurrence in the Cretaceous region of Central Russia. In that area, however, the Senonian and higher Cretaceous stages are not well developed, though they assume greater importance in the southern part of the Empire.[1]

Denmark.—The Danian stage receives its name from its typical development in the east of Denmark. Its lower portion or Faxoe Chalk is a hard yellowish limestone full of bryozoa with *Nautilus danicus, Temnocidaris, Dorocidaris, Holaster, Brissopneustes, Corallium Becki*. Its upper division or Saltholm limestone is another compact kind of chalk with flints containing *Nautilus danicus, Baculites Faujasi, Belemnitella mucronata, Ostrea vesicularis, Terebratula carnea, Echinocorys* (*Ananchytes*) *sulcatus*. This rock has been found by boring and well-sinking to cover a wide tract around Copenhagen under the glacial Drift. It is in places overlain by a fossiliferous greensand.[2]

Scandinavia.—The districts of Malmö, Ystad, and Christianstad in the south of Sweden present an interesting development of the Senonian and Danian stages. The Lower Senonian marls contain *Actinocamax verus, A. westphalicus* and *Inoceramus cardissoides*. The Upper Senonian beds, consisting in the lower part of limestones and conglomerate, are marked by the presence of *Actinocamax mammillatus, Pecten septemplicatus, Ostrea acutirostris*, while the higher part, composed at Malmö of soft chalk and elsewhere of sandstone and limestone, yields *Belemnitella mucronata, Echinocorys* (*Ananchytes*) *ovatus, Terebratula carnea* and other characteristic fossils. The highest member of the series representing the Danian stage contains *Echinocorys* (*Ananchytes*) *sulcatus, Terebratula lens, Dromia rugosa*, &c.[3] The remains of a bird (*Scaniornis Lundgreni*) have been obtained from the Saltholm Limestone near Malmö.[4]

Arctic Regions.—The Cretaceous system has been found to extend even as far north as Lat. 79° into Spitzbergen and King Charles Land. On the latter islands Professor Nathorst has found, underneath the overlying basalt plateau, strata which he believes to be of Neocomian age containing *Aucella Keyserlingi* and remains of plants.[5] Again, on the west coast of Greenland, between the parallels of 70° and 71° N., a thick mass of strata underlying the basalts appears to be divisible into three groups, of which the

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1 Nikitin, 'Les Vestiges de la periode Crétacée dans la Russie centrale,' *Mem. Com. Geol. Russe*, v. No. 2 (1888), p. 165. W. F. Hume, *Geol. Mag.* 1892, p. 385.

2 C. Schlüter (*Z. D. G. G.* xlix. (1897), pp. 38, 889) gives an account of the Cretaceous succession in the Baltic with a bibliography of the subject, and descriptions of a number of new urchins from the region. K. Rördam, "Kridt formationen i Sjæland," *Danmarks Geol. Undersög*, 1897, describes the White Chalk (uppermost Senonian), the Saltholm Limestone and the greensand, above mentioned, containing gasteropods, lamellibranchs, &c., which is the youngest member of the Cretaceous series in Denmark. Another important recent contribution to the Cretaceous palæontology of the Baltic region is that by J. P. Ravn, "Molluskerne i Danmarks Kridtaflejringer," *K. Dansk. Vidensk. Selsk. Skrift.* xi. (1902) parts 2 and 4.

3 B. Lundgren, *Universitets Äriskrift.* Lund. xxiv. (1888); *Geol. Fören. Stockholm*, xi. (1889), p. 63. H. Munthe, xviii. (1896), p. 21. A. Hennig. xx. (1898), p. 79; xxi. (1899), pp. 19-82, 133-188. J. C. Moberg. *Neues Jahrb.* ii. (1894), p. 69.

4 W. Dames, *Bihang. Svensk. Vet. Akad. Handl.* xvi. (1890).

5 *Geol. Fören. Stockholm*, xxiii. (1901), p. 341.

lowest or Kome series has yielded a remarkable assemblage of fossil plants, including the *Populus primæva*, which was long believed to be the oldest dicotyledon. The plants comprise *Gleichenia* (several species), *Asplenium*, *Pecopteris*, *Zamites*, *Nilssonia*, *Sequoia*, *Pinus*. In the next or Atane series dicotyledons outnumber the ferns, cycads, and conifers. They belong to species of *Populus*, *Platanus*, *Hedera*, *Ficus*, *Cassia*, *Laurus*, *Quercus*, &c. Among the plant-bearing strata certain shales occur bearing a marine fauna (*Pecten*, *Arca*, *Nuculana*, *Lucina*, *Cuspidaria*, *Dentalium*, &c.), which appears to be of Upper Cretaceous age. This horizon may perhaps be paralleled with the Amboy Clays of the United States. The Patoot series contains a younger flora, which indicates a transition towards a Tertiary facies. It includes species of *Gleichenia*, *Aspidium*, *Sequoia*, *Arundo*, *Platanus*, *Quercus*, *Viburnum*, *Rhamnus*, &c., and with it are associated bands containing marine fossils (*Hemiaster*, *Avicula*, *Dentalium*, &c.).[1]

India.—The hippurite limestone of south-eastern Europe is prolonged into Asia Minor, and occupies a vast area in Persia. It has been detected here and there among the Himalaya Mountains in fragmentary outliers. Southward of these marine strata, there appears to have existed in Cretaceous times a wide tract of land, corresponding on the whole with the present area of the Indian peninsula, but possibly stretching south-westwards so as to unite with Africa. On the south-eastern side of this area the Cretaceous sea extended and deposited a succession of strata which have been paralleled with the European Upper Cretaceous formations, and have been divided into the following groups in ascending order: (1) Utatur group, containing at its base large masses of coral-reef limestone and yielding no less than 300 species of invertebrates, more than 100 of these being cephalopods, of which 27 are known to occur in Europe or elsewhere out of India. Some of these are Neocomian species, but the general character of the fossils indicates that this group may be equivalent to the Cenomanian series of Europe. (2) The Trichinopoli group, composed of sands, clays, limestones and conglomerates lying unconformably on the first group. The fossils are here not so numerous as in the beds below, and the cephalopods are much diminished in number. The group appears to represent the European Turonian stage. (3) The Ariyalur group, the most highly fossiliferous of the three divisions. Here gasteropods replace cephalopods, the Cypræidæ and Volutidæ being specially prominent. The presence of *Nautilus danicus* points to the position of this group at the top of the system. Similar strata appear on the African coast in Natal, where they are capable of palæontological subdivision into three zones like those of India, and contain many of the same species of fossils.[2] The most remarkable episode of Cretaceous times in the Indian area was undoubtedly the colossal outpouring of the Deccan basalts (p. 346). These rocks, as already remarked, in horizontal or nearly horizontal sheets, attain a vertical thickness of from 4000 to 6000 feet or more, and cover an area of at least 200,000 square miles, though their limits have no doubt been reduced by denudation. Their oldest portions lie slightly unconformably on Cenomanian rocks, and in some places appear to be regularly interstratified with the uppermost Cretaceous strata. The occurrence of fresh-water mollusks (*Physa*, *Viviparus*, *Unio*, *Corbicula*), lands-plants, and insects, both in the lowest and highest parts of the volcanic series, proves that the lavas must have been subaerial. This is one of the most gigantic outpourings of volcanic matter in the world.[3]

Japan.—The labours of the active Geological Survey of Japan have brought to light a remarkably full development of the Cretaceous system in that country, and have

[1] Heer, 'Flora Fossilis Arctica'; De Saporta, 'Le Monde des Plantes'; D. White and C. Schuchert, *Bull. Geol. Soc. Amer.* ix. (1898), p. 343.

[2] F. Kossmat, *Jahrb. k. k. Geol. Reichsanst.* xliv. (1894), p. 463; R. B. Newton, *Journ. Conchology*, viii. (1896), p. 136.

[3] Medlicott and Blanford, 'Geology of India,' 2nd edit. by R. D. Oldham, chaps. x. and xi. See also F. Stoliczka, *Palæontograph. Indica*, ser. i. iii. v. vi. and viii. (1861-1873).

supplied the means of comparing the faunas and floras of that system on the opposite sides of the great Pacific basin. At the base lies a limestone (Torinosu) containing a rich fauna of foraminifera, corals, bryozoa, echinoids, lamellibranchs, and gasteropods, while in some places it includes intercalated plant-beds with *Zamiophyllum*, *Nilssonia*, *Podozamites*. It is regarded as probably Neocomian. The Ryoseki series is distinguished by its varied and abundant flora, consisting of ferns, lycopods, cycads, and conifers, many of the species being found in the Cretaceous series of India, Europe, the Potomac formation of America and the Kome beds of Greenland. No dicotyledons are recorded in the published list. The Izumi sandstones contain both marine shells and land-plants. Among the former are species of *Pachydiscus*, *Anisoceras*, *Macroscaphites*, *Phylloceras*, *Hamites*, *Helicoceras*, *Inoceramus*, *Avicula*, and *Trigonia pocilliformis*, which is the most characteristic fossil of the whole. The plants include species of *Arundo*, *Salix*, *Quercus*, *Fagus*, *Platanus*, *Cinnamomum*. *Sequoia*. Perhaps of the same age as these sandstones is the important Hokkaido series, which consists of sandstones, conglomerates, and shales with plant-bearing shales and coal-seams at the top. The middle and lower parts of this series have furnished a large assemblage of fossils, including nine species of *Desmoceras*, twelve of *Hamites*, eight of *Lytoceras*, eight of *Pachydiscus*, together with several species of *Anisoceras*, *Acanthoceras*, *Olcostephanus*, *Scaphites*, and *Crioceras*. A number of the organisms are specifically identical with those found at Trichinopoli and other Cretaceous localities of India. The formation may represent the Middle and Upper Cretaceous series of Europe.[1]

North America.—The Cretaceous system stretches over a vast portion of the American continent, and sometimes reaches an enormous thickness. Sparingly developed in the eastern States, it runs as a belt from Long Island across New Jersey, Delaware, and Maryland into Virginia. It spreads out over a wide area in the south, stretching round the end of the long Palaeozoic ridge from Georgia through Alabama and Tennessee to the Ohio; and reappearing from under the Tertiary formations on the west side of the Mississippi over a large space in Texas and the south-west. Its greatest development is reached in the Western States and Territories of the Rocky Mountain region, Wyoming, Utah, and Colorado, whence it ranges northward into British America, covering thousands of square miles of the prairie country between Manitoba and the Rocky Mountains, and stretching westwards even as far as Queen Charlotte Islands, where it is well developed. It has a prodigious northward extension, for it has been detected in Arctic America near the mouth of the Mackenzie River.

The eastern belt, which runs from Long Island[2] into Virginia, is full of geological interest, and has given rise to prolonged discussion. It is divisible broadly into two series, of which the older is termed Lower and the younger Upper Cretaceous. The former, widely known as the Potomac formation, has been more particularly the field of controversy, some writers claiming it for the Jurassic system, others as confidently asserting it to be Cretaceous (p. 1159). Of the former class the late Professor Marsh brought forward the most cogent arguments based on the occurrence of deinosaurian remains having Jurassic affinities. One species of *Astrodon* was named by Leidy, and a number of other vertebrates by Marsh (*Pleurocœlus*, *Priconodon*, *Allosaurus*, *Cœlurus*, besides crocodiles, tortoises, fishes, and mollusks). On the other hand, the evidence of the Potomac flora has been confidently appealed to as affording an unquestionable proof of the Cretaceous age of the strata in which it is preserved. An important contribution to this controversy has been recently made by Professor W. B. Clark and Mr. A.

[1] 'Outlines of the Geology of Japan,' by the Imperial Geol. Survey of Japan. Tokyo, 1900, p. 59.

[2] The Cretaceous plant-bearing strata of Long Island have been described by A. Hollick, *Trans. New York Acad. Sci.* xii. (1893), pp. 189, 222; xiii. (1893), pp. 8, 122; *Bull. Torrey Botan. Club*, xxi. 1894.

Bibbins, who have clearly shown that the so-called Potomac formation really consists of a series of formations quite distinct from each other, lithologically, stratigraphically, and palæontologically. They maintain that a marked line of division can be drawn above which the vertebrate remains have never been found, and below which the dicotyledonous flora never descends. They are disposed to class the formations below that line (which they name the Patuxent and Arundel groups) as probably Jurassic, but they regard those which lie above the line as undoubtedly Lower Cretaceous. These latter they reckon as two in number. The lower, or Patapsco, consists of highly coloured and variegated clays and sands, some of which are full of leaf-impressions, the thickness of the whole ranging up to fully 200 feet. These strata lie with a marked unconformability on the Arundel group underneath. Their fossils include a few poorly preserved mollusca, but consist mainly of land-plants, ferns, cycads, conifers, monocotyledons and dicotyledons. Higher up comes the Raritan formation, which is also composed of sands and clays, with beds of brown earthy lignite, and in Central Maryland reaches a thickness of nearly 500 feet. Its fossils likewise consist mainly of land-plants, the dicotyledons showing a markedly more modern aspect than those of the Patapsco beds below.[1]

The flora of the Potomac series has been carefully studied by the ablest palæobotanists of America.[2] A census published in 1896 gave the total number of species then known as 737, which have been obtained from five distinct horizons.[3] The dicotyledons numbered nearly half of the whole. Those found in the older part of the formation have a primitive character (*Ficophyllum*, *Protecæphyllum*, *Rogersia*, *Saliciphyllum*, *Vitiphyllum*). The others include species of *Andromeda*, *Aralia*, *Cinnamomum*, *Eucalyptus*, *Ficus*, *Hedera*, *Ilex*, *Juglans*, *Laurus*, *Magnolia*, *Myrica*, *Platanus*, *Quercus*, *Rhamnus*, *Salix*, *Sapindus*, *Sassafras*, *Viburnum*. Some of the plants are identical with species found in the Lower Cretaceous series of England, Germany, and Portugal.

The Upper Cretaceous formations of the same eastern belt lie transgressively upon the Lower series. They are arranged as follows in ascending order:—(1) Matawan, composed chiefly of sands and clays, about 400 feet thick in New Jersey, but gradually thinning southwards until towards the Potomac River they disappear. These strata have furnished a considerable number of shells of thoroughly marine character, including *Placenticeras placenta*, *Scaphites nodosus*, *Baculites ovatus*, and species of *Pyropsis*, *Gyrodes*, *Scalaria*, *Turritella*, *Dentalium*, *Ostrea*, *Gryphæa*, *Inoceramus*, *Crassatella*, *Cardium*, *Terebratula*, also *Hemiaster*, &c. (2) Monmouth, lying conformably on No. 1, and consisting chiefly of sands, ferruginous and glauconitic, which vary from 60 to 150 feet in thickness, but disappearing in the direction of Washington. Fossils are here strikingly abundant and well preserved, some of the layers consisting of an aggregate of shells. Among them are *Belemnitella americana*, *Baculites ovatus*, *Nautilus Dekayi*, with a large assemblage of gasteropods and lamellibranchs, as well as brachiopods, foraminifera, &c. (3) Rancocas, composed chiefly of greensand marls, sometimes highly calcareous, usually between 40 and 50 feet thick, but reaching a maximum of 125 feet. Though less varied in species, the fossils are individually abundant. They comprise *Sphenodiscus lenticularis*, *Nautilus Dekayi*, *N. Bryani*, *Teredo tibialis*,

[1] W. B. Clark and A. Bibbins, *Journ. Geol.* v. (1897), p. 479.

[2] See particularly W. M. Fontaine, *Monograph* xv. *U.S. G. S.* (1889); *B. U.S. G. S.* No. 145 (1896). J. S. Newberry, *Monograph* xxvi. *U.S. G. S.* (1896). L. F. Ward, *Ann. Rep. U.S. G. S.* 1895 and 1896. A list of 50 species of the Cretaceous plants from Long Island is given by A. Hollick in his paper above cited. Professor Ward has subdivided the formation into six series, which in ascending order are (1) James River, (2) Rappahannock, (3) Mount Vernon, (4) Aquia Creek, (5) Iron Ore, (6) Alburipean (Amboy and Raritan).

[3] These are named in the foregoing note.

Hemiaster (several species), *Cardiaster, Ananchytes, Pseudodiadema, Salenia, Cidaris, Pentacrinus*, &c. (4) Manasquhan, a group of highly glauconitic greensands, 50 feet thick in the north, but disappearing southwards, owing to the unconformable overlap of the Tertiary formations. Its fossils are neither numerous nor varied. They comprise some lamellibranchs (*Ostrea, Gryphæa, Crassatella*) and a number of foraminifera (*Textularia, Nodosaria, Globigerina bulloides*).[1]

The Cretaceous formations, which stretch as a narrow belt between the older crystalline rocks and the overlying Tertiary deposits through the States of Georgia, Alabama, Mississippi, and Tennessee, display both the lower and upper divisions of the system. The lower is well developed in Alabama, where it forms the Tuscaloosa formation, about 1000 feet thick, composed of purple, mottled and grey clays overlain with variegated sands. It has yielded a number of plants, which, according to Professor L. F. Ward, show it to be the equivalent of the Amboy and Raritan clays at the top of the Potomac formation. There would thus appear to be a continuous belt of Lower Cretaceous plant-bearing clays and sands from Long Island into Mississippi, a distance of more than 1000 miles. These deposits were formed in sheltered waters fringing a well-wooded land-surface, and were eventually submerged under the sea which spread westwards over the sinking land and laid down the Upper Cretaceous marine strata.

The depression which led to the deposition of the New Jersey and Maryland marine clays and sands appears to have begun earlier, and to have been on a more extended scale in the southern States. It brought about the accumulation of the thick pelagic formations which play so large a part in the geology and scenery of the region around the borders of the Gulf of Mexico. These formations in central Texas have a thickness of about 1500 feet, but they increase south-westwards until, on the Mexican frontier, they reach 4000 or 5000, and are said to swell out to even three or four times that bulk in Mexico itself. The Texas Lower Cretaceous deposits, sometimes termed the Comanche series, have been divided into three formations, the Trinity, Fredericksburg, and Washita. (1) At the bottom lies the Trinity, consisting of (*a*) sands overlain by (*b*) Glen Rose limestones and clays, and these by (*c*) the Paluxy sands. This formation has yielded a number of land-plants having a general resemblance to and in part an identity with those of the Potomac flora, though, as they include no angiosperms, Fontaine believed that they may perhaps be a little older. But higher up the fossils are chiefly marine, and though connecting species run from one zone into another, several distinct faunas have been recognised. The Trinity formation is marked by the presence of *Ostrea Franklini, Trigonia crenulata, Requienia texana, Glauconia helvetica*. The general assemblage has a marked resemblance to the fauna of the Lower Cretaceous series of Portugal. (2) The Fredericksburg formation, composed of (*a*) Walnut clays, (*b*) Comanche Peak Limestone, (*c*) Caprina (Edwards) limestone. In the lower part of this series of strata *Natica, Tylostoma*, and *Gryphæa* are prevalent, together with echinoids (*Hemiaster, Holaster, Holectypus, Pseudodiadema, Cidaris*) and three important ammonites (*Eugonoceras piedernalis, Schlœnbachia acutocarinata*, and *S. trinitensis*). The Caprina limestone at the top of the formation "has an interesting and remarkable fauna, consisting largely of Requienia, Monopleura, Ichthyosarcolites, and other Chamidæ, with Radiolites or Sphærulites, Nerinea, many other gasteropods, corals, &c. The general assemblage of forms is very much like that in the 'Schrattenkalk' or 'Caprotina limestone' of the European Urgonian, and the similarity extends to specific forms in many cases." (3) The highest formation, termed the Washita, consists of four groups: (*a*) Preston beds, (*b*) Fort Worth limestone, (*c*) Denison Beds, (*d*) Shoal Creek limestone. Many of the organisms of the underlying formation recur here. Ammonoids are more abundant than in any other part of the series. They include *Pachydiscus brazoensis, Hamites Tremonti*,

[1] W. B. Clark, *Bull. Geol. Soc. Amer.* viii. (1897), pp. 315-358.

with a large development of the genus *Schlœnbachia*, mostly of the type of the European *S. inflata* (*rostrata*) and *Turrilites brazoensis*. These strata are succeeded by others, which, containing species of *Acanthoceras* and other Cenomanian types, are placed at the base of the Upper Cretaceous series.[1] This series in Texas consists of the following formations in ascending order: (1) Timber Creek, coarse sandstones and some impure limestone (*Acanthoceras*, &c.), about 250 feet thick; (2) Eagle Ford shales with layers of limestone and sandstone, 300 feet, containing *Ostrea congesta*, *Exogyra columbella*, *Inoceramus exogyroides*, *Buchiceras Swalovi*, *Mortoniceras shoshonense*, and probably the equivalent of the Benton group farther north; (3) Austin limestone—an important and persistent band of light grey abundantly fossiliferous limestone, with *Ostrea congesta*, *Inoceramus* (several species), *Nautilus elegans*, *Mortoniceras vespertinum*, *M. shoshonense*, *Baculites asper*, probably representing the Niobrara group of the interior to the north; (4) "Ponderosa" marls, estimated to be 1200 feet thick; (5) Glauconite beds, 300 feet; (6) Laramie group with lignites.

In Kansas the Lower Cretaceous or Comanche series, in diminished proportions, has been separated into two formations. The lower, termed the "Cheyenne Sandstone," attains a thickness of from 40 to 70 feet, and has yielded only plant remains (*Rhus*, *Sassafras*, *Glyptostrobus*, *Sequoia*), which point to a horizon not far from that of the upper clays of the Potomac series. The upper formation, called the "Kiowa Shales," consists chiefly of shales from 70 to 150 feet in thickness, which have furnished 78 species of fossils, vertebrate and invertebrate, showing marine conditions of deposit (*Gryphæa*, *Exogyra*, *Cardium*, *Avicula*, *Schlœnbachia*, &c.). Above these strata lies the formation known as the "Mentor (Dakota) Sandstone" of Kansas, which at its base has a band of brown fossiliferous sandstone with *Ostrea*, *Gervillia*, *Trigonia*, and other shells.[2]

The Black Hills of Dakota display an exceedingly interesting inlier of Archæan and Palæozoic rocks, round which the Mesozoic formations have been upraised. The Triassic, Jurassic, and Cretaceous formations follow each other in successive rings around the uplifted area. The Cretaceous series, resting upon the upper Jurassic strata, has at its base a group of fresh-water sandstones and clays with workable coal-seams, from which nearly 100 species of plants have been obtained and described. While most of them are ferns, cycads, and conifers, they include a number of dicotyledons, among which are species of *Quercus*, *Ficophyllum*, *Sassafras*, *Platanus*, *Sapindopsis*, *Viburnites*, &c. Dr. Ward shows that the flora is essentially Lower Cretaceous, and he compares it with that of the Wealden and Neocomian formations of Europe.[3]

In the vast interior region which stretches from Kansas westward into Colorado and Utah and northward through Nebraska, South and North Dakota, Wyoming, and Montana into the western part of the British possessions, an enormous accumulation of Upper Cretaceous formations records a remarkable succession of geological changes on a grand scale. Extensive inland bodies of water received the drainage of the surrounding land and became the sites of thick deposits of sands, clays, and lignites, among which the vegetation and many of the fishes and terrestrial animals of the time have been preserved. A widespread depression allowed the sea to spread over these lacustrine areas for a time, and to leave behind a record of marine deposits. There would appear to have been oscillations of level leading to an alternation of salt and fresh-water accumulations. But eventually the lacustrine conditions were restored on a greater scale than ever, until a succession of lakes and alluvial river-plains extended from Mexico far north into Yukon, a distance of more than 2000 miles, with a breadth of sometimes 400 or 500 miles. This succession of events has been chronicled in a series

[1] T. W. Stanton, *Journ. Geol.* v. (1897), pp. 600-607.

[2] C. S. Prosser, *University Geol. Survey Kansas*, ii. (1897), p. 196.

[3] Lester F. Ward, 19*th Ann. Rep. U.S. G. S.* 1899.

of geological formations which are arranged as in the subjoined table in descending order :—

Livingstone Formation.—A series of sandstones, grits, conglomerates, and clays, largely made up of the debris of andesitic lavas and other volcanic rocks, and including local intercalations of volcanic agglomerates, the whole amounting to a thickness of 7000 feet. This formation was first separated in 1893 by Mr. W. H. Weed, who showed that it indicates an uplift and abrasion of the underlying members of the Cretaceous series, with a great succession of volcanic explosions, by which enormous quantities of angular lava-detritus were discharged into the lake. These eruptions towards the close of the Cretaceous period were the forerunners of the series which took place on so gigantic a scale in Tertiary time. A meagre molluscan fauna has been obtained from these strata, apparently belonging to brackish, fresh-water, and terrestrial species. Much more abundant and determinable are the land-plants found towards the base of the formation in the leaf-beds, which range from 600 to 2000 feet in thickness. Among these plants are species of *Abietites*, *Taxodium*, *Ginkgo*, *Phragmites*, *Populus*, *Salix*, *Quercus*, *Juglans*, *Platanus*, *Ficus*, *Cinnamomum*, *Laurus*, *Fraxinus*, *Andromeda*, *Rhamnus*.[1]

Laramie formation.—The chief coal-bearing series of the Rocky Mountains, consisting of buff and grey sandstones, with bands of dark clays and numerous coal-seams, containing abundant terrestrial vegetation, land and fresh-water mollusks (*Unio*, *Limnæa*, *Planorbis*, *Helix*, *Pupa*, &c.), and remains of fishes (*Lepidotus*), turtles (*Trionyx*, *Emys*, *Compsemys*), and reptiles (*Crocodilus*, *Agathaumas* (*Triceratops*), &c.). Marine organisms in some intercalated strata show that the sea still occasionally spread over the lacustrine region. In this formation come the "Ceratops beds" of Wyoming, which, resting directly upon the Fox Hills group, consist of alternating sandstones, shales, and lignites, and are remarkable for the extraordinary number and wonderful preservation of the deinosaurs, mammals, and other forms which they have yielded.

The Laramie formation was originally termed "Lignitic," and was made to include all the vast series of lignite-bearing formations of the Western Territories. Its limits have now been restricted both below and above. Its lower limit is now placed at the top of the Fox Hills group. The Livingstone formation has been cut off from its upper part, so that in Montana its thickness has been reduced to 1000 feet.

Montana formation.—A series of lacustrine and brackish-water deposits containing important coal-seams and an abundant terrestrial flora, with intercalations of marine bands. The flora embraces 89 forms, which include 63 species of dicotyledons, 10 conifers, 4 monocotyledons and some ferns, lycopods, and other plants.[2] The formation reaches in Utah a thickness of 2800 feet. It is subdivided into two groups, which, however, cannot always be distinguished :—

Fox Hills group.—Grey, rusty, and buff sandstones, with numerous beds of coal and interstratifications containing a varied assemblage of marine shells (*Belemnitella*, *Nautilus*, *Ammonites*, *Baculites*, *Mosasaurus*, &c.).

Fort Pierre group.—Carbonaceous shales, marls, and clays, *Ostrea congesta*, *Inoceramus Cripsii*, var. *Barabini*, *Avicula fibrosa*, *Lucina occidentalis*, *Chlamys nebrascensis*, *Baculites ovatus*, *Scaphites nodosus*, Ammonites, &c.).

Colorado formation.—Calcareous shales and clays with a central sandy series, and, in the Wahsatch region, seams of coal as well as fluviatile and marine shells. Thickness in Kansas 340 to 380 feet, east of the Rocky Mountains 800 to 1000 feet, but westwards in the region of the Uinta and Wahsatch Mountains 2000 feet. This group has yielded a large marine fauna. Among its ammonoids are species of *Helicoceras*, *Baculites*, *Buchiceras*, *Placenticeras*, *Prionocyclus*, *Prionotropis*, *Mortoniceras*, *Scaphites*, some of them being also well-known European forms, such as *Nautilus elegans*, *Prionotropis Woolgari*, *Acanthoceras Mantelli*.[3] The formation is subdivided into two groups :—

[1] W. H. Weed, *Bull. U.S. G. S.* No. 105 (1893), with appendix on the plants by F. H. Knowlton.

[2] F. H. Knowlton, *Bull. U.S. G. S.* No. 163 (1900).

[3] T. W. Stanton, "The Colorado Formation and its Invertebrate Fauna," *Bull. U.S. G. S.* No. 106 (1893).

Niobrara group.—Chalky marls, chalk, shales, with large calcareous concretions and seams of limestone (*Baculites, Belemnites, Uintacrinus, Inoceramus deformis, I. problematicus, Ostrea congesta, Rudistes*). The most interesting and important organic remains furnished by this group belong to vertebrates. From the Niobrara beds of Kansas have been obtained six genera of Mosasaurs (*Clidastes, Tylosaurus, Platecarpus, Holosaurus, Sironectes, Baptosaurus*) several species of pterodactyle, as well as plesiosaurs, turtles, and above all the toothed birds first described by Marsh.

Benton group.—Shales, clays, and limestones (*Scaphites warrenensis, Prionotropis Woolgari, Ostrea congesta, Inoceramus*, several species, and sometimes in great abundance).

On the Bear River in south-western Wyoming an important series of argillaceous calcareous shales, alternating with thin beds of sandstone, appears to occupy a position intermediate between the Colorado and Dakota formations, and may be a lacustrine representative of part of one or other or both. It has yielded a large molluscan fauna, belonging chiefly to fresh-water and terrestrial species, but with a few brackish-water forms. Among them are species of *Ostrea, Modiola, Unio, Corbicula, Auricula, Limnæa, Planorbis, Physa, Neritina, Pachymelania, Hydrobia*, and *Viviparus*.[1]

Dakota formation, consisting of yellow and grey massive (probably lacustrine) sandstones, sometimes with clays and seams of coal or lignite (dicotyledonous leaves in great numbers, *Ficus, Sassafras, Platanus, Juglans*, &c.). In the Wahsatch region there lies at the base a persistent and coarse conglomerate, sometimes 200 feet thick. Thickness of the formation, 400 feet and upwards. In some places there are marine intercalations in this group, showing that the sea lay not far off the area of deposit. Thus in Kansas, the lower part of the formation, consisting of sandstones and shales with terrestrial plants and seams of lignite, is overlain with saliferous and gypseous shales containing *Corbicula, Cyrena, Yoldia, Crassatellina, Tellina, Mactra*, &c.[2]

Cretaceous formations are largely developed along the Pacific slope, where they reach a great thickness in the coast-ranges, and where they have undergone in some places much metamorphism.[3] In California a section of Cretaceous strata on Elder Creek, Tehama County, gives a thickness of about 30,000 feet without any evidence of duplication.[4] This pile of sediment, which is known as the Shasta-Chico series, is on the whole of marine origin. It has been subdivided into three series, which in ascending order are (1) Knoxville, (2) Horsetown and (3) Chico. The Knoxville Beds, with an apparent thickness of 20,000 feet, consist mainly of shales and shaley sandstones with calcareous layers. They have furnished a considerable number of ammonoids (15 species, including the genera *Phylloceras, Lytoceras, Desmoceras, Olcostephanus, Hoplites, Perisphinctes, Crioceras*), with belemnites, many gasteropods (*Fissuridea, Pleurotomaria, Turbo, Amberleyia, Cerithium, Aporrhais*), lamellibranchs (*Pecten, Aucella*, very abundant,

[1] C. A. White, *Bull. U.S. G. S.* No. 128 (1895).

[2] W. N. Logan, *Kansas Geol. Surv.* ii. (1897), p. 202.

[3] Some difference of opinion has risen as to how far the Cretaceous rocks have been involved in the metamorphism which has affected the Triassic and Jurassic series. Whitney and afterwards Becker (*Amer. Journ. Sci.* xxxi. (1886), p. 347) affirmed that they have, others, especially H. W. Fairbanks (*Amer. Geologist*, 1892, 1893 ; *Bull. Geol. Soc. Amer.* vi. (1894), p. 71), have advocated the opposite opinion. There can be little doubt that there was an extensive protrusion of granitic and other igneous material after some part at least of the Jurassic formations had been deposited. Mr. J. P. Smith believes that the Mariposa auriferous slates are of Jurassic age (*Bull. Geol. Soc. Amer.* v. (1897), p. 257).

[4] This section was measured and tabulated by Mr. J. S. Diller and J. Stanley-Brown (*Bull. Geol. Soc. Amer.* v. (1894), p. 438), who could find no evidence of reduplication, though they admit that the evidence for such an almost incredible thickness is not irrefragable. Even if we reduce the mass to half these dimensions it remains an enormous mass of sedimentary material.

Inoceramus, Nucula, Astarte, Lucina, Cyprina, Corbula) and brachiopods (*Rhynchonella, Terebratula*). The Horsetown formation presents a somewhat similar lithology and fauna, but with some differences. Ammonites are locally abundant in its lower part, those of the genera *Lytoceras* and *Phylloceras* being especially well represented in individuals.[1] The remarkably abundant *Aucellæ* (the most characteristic fossils of the Knoxville beds) do not ascend above the limit which has been taken as the base of the Horsetown beds. In the higher part of this formation among the ammonoids the familiar European form *Schlœnbachia rostrata*, another closely allied to *Douvilleiceras mammillatum*, and a third, which may be Brongniart's *Desmoceras Beudanti*, have been noted. It would thus seem that while the Knoxville beds are referable to the Neocomian series, the Horsetown include the rest of the Lower Cretaceous formations, possibly extending into the upper division of the system. The Chico beds in the Elder Creek section were found on measurement to be 4000 feet thick. They are chiefly composed of conglomerates and sandstones, and have yielded a good many marine organisms. In their lower 1500 feet are found *Desmoceras, Actæon, Anchura, Gyrodes, Tellina, Chione, Meekia, Trigonia*, &c., while towards the top *Inoceramus Whitneyi* and *Pachydiscus newberryanus* are met with.[2]

While this vast accumulation of sediments represents almost entirely the accumulations of the sea-floor it includes occasional platforms which have preserved remains of the terrestrial vegetation of the time. At a height of about 8000 feet above the base of the Knoxville series a plant-bed occurs from which a number of ferns and cycads have been collected, but no dicotyledons appear in the list. Another band at the top of the formation, together with marine shells (*Aucella crassicollis, Desmoceras* sp. *Olcostephanus mutabilis* and *Lytoceras Batesi*) has furnished specimens of *Sagenopteris Mantelli* and *Pterophyllum californicum*, the plants being directly associated with the *Aucellæ*.[3] The Horsetown formation also contains near its base a highly fossiliferous band which, besides *Belemnites impressus, Hoplites* sp. *Olcostephanus Traski, Lytoceras Batesi*, &c., has yielded *Nagliopsis latifolia, Angiopteridium nervosum, A. oregonense*.

The Cretaceous system is prolonged into British North America, where it is well developed not only on the Pacific slopes but on the east side of the Rocky Mountains in Manitoba and the North-West Territories. In Vancouver and adjacent islands a series of strata, known as the Nanaimo group, has furnished a large series of organic remains, which, like the formations in the Western United States, whereof they are no doubt prolongations, include both marine shells and terrestrial plants. The strata, about 5000 feet in thickness, consist largely of conglomerates and shales with a group of coal-bearing strata 740 feet thick at their base. Among the marine organisms are *Phylloceras Velledæ, P. Indra, Lytoceras Jukesii, Anisoceras vancouverense, Hamites obstrictus, Desmoceras Gardeni, Pachydiscus ootacodensis, P. Haradai, Belemnites*, &c. The plants include many dicotyledons, palms, and other forms. This series is regarded as Upper Cretaceous, and is not improbably a continuation of the Chico series of California. Apparently of somewhat older date is the coal-bearing series in the Queen Charlotte group, of which the subjoined section occurs at Skidegate Inlet.[4]

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[1] T. W. Stanton, "The Fauna of the Knoxville Beds," *Bull. U.S. G. S.* No. 133 (1895); *Journ. Geol.* v. (1897), p. 594.

[2] Stanton, *B. U.S. G. S.* No. 133, p. 16; Diller and Stanton, *Bull. Geol. Soc. Amer.* v. (1894), p. 439.

[3] Stanton, *B. U.S. G. S.* No. 133, p. 17.

[4] J. Richardson in *Report of Progress of Geol. Surv. Canada*, 1871-77. G. M. Dawson, *op. cit.* 1878-79, 1886; *Amer. Journ. Sci.* xxxviii. (1889), p. 120; *op. cit.* xxxix. (1890), p. 180. J. F. Whiteaves, *Mesozoic Fossils*, vol. i. Parts i. iii. in publications of *Geol. Survey, Canada;* Presidential Address, *Trans. Roy. Soc. Canada*, sect. iv. 1893. See also Dr. Dawson's *Report on Geology and Resources of the Region near the 49th Parallel, British North American Boundary Commission*, 1875; *Report on Canadian Pacific Railway*, Ottawa, 1880.

Upper shales and sandstones. (Few fossils, the only form recognised being *Inoceramus problematicus*)	1,500 feet.
Conglomerates and sandstones (fragments of *Belemnites*) . . .	2,000 „
Lower shales and sandstones with a workable seam of anthracite at the base (fossils abundant, including *Schlœnbachia rostrata* (*inflata*), *Desmoceras Beudanti*, *D. planulatum*, *Lytoceras timotheanum*, *Perisphinctes*, *Belemnites*, *Inoceramus concentricus*, &c.) . .	5,000 „
Volcanic agglomerates, sandstones, and tuffs, with blocks sometimes four or five feet in diameter	3,500 „
Lower sandstones, some tufaceous, others fossiliferous . . .	1,000 „
	13,000 „

The middle Cretaceous formations of the North-West Territory have yielded a remarkable assemblage of vertebrate remains, which have been discussed and described by Prof. Osborn and Mr. Lambe. The Belly River series, which is said to underlie the Montana or Fort Pierre-Fox Hills groups, and overlies the Fort Benton and Dakota groups, has furnished well-preserved remains of fishes (*Lepidotus*, &c.), plesiosaurs (*Cimoliosaurus*), chelonians, rhynchocephalia (*Champsosaurus*), crocodiles (*Crocodilus*, *Bottosaurus*), megalosaurs (*Deinodon*), stegosaurs (*Palæoscincus*, *Stereocephalus*), ceratopsia (*Monoclonius*, *Stegoceras*), iguanodons (*Cionodon*, *Trachodon*), and mammals (*Ptilodus*, *Boreodon*).[1]

Farther north marine and coal-bearing strata of Cretaceous age have been found to extend into Yukon. The plants obtained from them include species of *Taxodium*, *Glyptostrobus*, *Corylus*, *Juglans*, *Sequoia*, while among the shells are *Discina Dawsoni*, *Cyprina yukonensis*, *Schlœnbachia borealis*, *Scaphites*, and in one place abundant specimens of one of the varieties of *Aucella mosquensis*.[2] On the eastern side of the Rocky Mountain axis Cretaceous formations in a plicated condition display the same commingling of marine organisms and terrestrial plants. From the botanical evidence Sir J. W. Dawson believed that he could make out three successive series among these strata. At the top he placed the Mill Creek series, which supplied him with some ferns, cycads, and dicotyledons, regarded as indicating a horizon not far removed from the Dakota formation. In the middle came his Intermediate series observed in Alberta, and containing *Asplenium*, *Glyptostrobus*, *Taxodium*, *Sterculia vetustula*, and *Laurus crassinervis*. The lowest series was that named Kootanie, from its occurrence at the Kooteny Pass, which originally furnished 27 species of plants, among which no species of angiosperms was detected.[3] The study of the invertebrate remains from the distorted Cretaceous rocks of the Foot Hills and Rocky Mountain ridges led to the recognition of what may be representatives of the United States series from the Dakota up to the Laramie formation. The Upper Cretaceous series appears to be widely spread over Manitoba and westward over the Great Prairie plateau in Alberta, Assiniboia, and Saskatchewan, where also the typical formations of the Western United States have been identified. An intermediate group, however, the "Belly River series" above referred to, has been intercalated between the Montana and Colorado formations. It is developed in Northern Alberta and Western Assiniboia. The plants in this series were found by Sir J. W. Dawson to include some deciduous species, which also occur in the Canadian Laramie group. The invertebrates are brackish or fresh-water shells, and the vertebrates include the interesting assemblage already mentioned.

South America.—The Cretaceous system has been found to be well developed even as far south as Patagonia, where the following succession of formations in ascending order has been ascertained by Mr. J. B. Hatcher. The oldest rocks visible are certain

[1] 'Contributions to Canadian Palæontology,' published by Canadian Geol. Surv., vol. iii. Part ii. (1902), by H. F. Osborn and L. M. Lambe.

[2] G. M. Dawson, *Ann. Rep. Geol. Surv. Canada*, 1889, pp. 1-227 B.

[3] *Trans. Roy. Soc. Canada*, iii. (1885), p. 11.

black, hard, fractured slates with obscure ammonites, possibly of Jurassic age. The lowest portion of the Cretaceous strata, named the Pueyrredon series, is about 800 feet thick. At its base lie soft green sands or marls with *Exogyra* (about 100 feet), surmounted by conglomerate (20 feet), with petrified wood perforated by small boring mollusks. Then come about 300 feet of soft greenish sandstones and clays (Belgrano beds), which towards the top are rich in remains of characteristic Mesozoic invertebrates indicative of Middle Cretaceous age. These strata pass up conformably into 330 feet of red and variegated sandstone and conglomerate. The Upper Cretaceous rocks forming the San Martin series are estimated to be 3500 feet thick, and appear to lie with a slight unconformability on the lower members of the system. They begin with a series of hard variegated sandstones (Areniscas Abigarradas beds, 1350 feet) yielding hardly any fossils, but covering a large extent of country, and giving rise to striking topography. Next in ascending order are the Lower Lignite beds (1500 feet), including vast quantities of tree-trunks, forming beds 20 to 30 feet thick. These are followed by the Guaranitic or Deinosaur beds (500 feet),—soft, dark or mottled clays and shales, with bright red, green, and orange layers, containing fairly abundant deinosaurian remains. These, which appear to be the youngest Cretaceous rocks in South America, are comparable with the Laramie group of the United States.[1]

Australasia.—Representatives of the Cretaceous system occupy a vast area in Australia. In Queensland their lower member ("Rolling Downs Formation") is estimated to cover three-fourths of the whole of the colony. This group of strata is found in some districts to pass down conformably into the plant-bearing Jurassic rocks, and elsewhere to lie unconformably on ancient schists, slates, and granites. It has yielded numerous species of foraminifera, brachiopods, lamellibranchs (*Ostrea vesiculosa*, *Pecten*, *Aucella*, *Inoceramus*, *Pinna*, *Mytilus*, &c.), gasteropods, belemnites, ammonites of the genera *Amaltheus*, *Schlœnbachia*, *Haploceras*, also *Hamites*, *Ancyloceras*, *Crioceras*, and *Nautilus*; likewise fishes of the genera *Lamna*, *Aspidorhynchus*, *Belonostomus*, and various ichthyosaurs and plesiosaurs. The Upper Cretaceous formations are represented by the "Desert Sandstone," which must itself have covered at least three-quarters of the colony. It lies on an upturned and denuded surface of the Lower Cretaceous formations and contains land-plants and a marine fauna (*Micraster*, *Rhynchonella*, *Ostrea*, *Trigonia*, *Belemnites*).[2]

In New Zealand the "Waipara" formation of Canterbury is believed to represent Upper Cretaceous and possibly some of the older Tertiary horizons. It consists of massive conglomerates (sometimes 6000 to 8000 feet thick), sandstones, shales, brown-coal seams, and ironstones. The plants include dicotyledonous leaves, cones and branches of araucarians, and leaves and twigs of *Dammara*. Among the shells no cephalopods nor any of the widespread hippurites have yet been found. With the remains of fishes (*Odontaspis*, *Lamna*, *Hybodus*) occur numerous saurian bones, which have been referred to species of *Plesiosaurus*, *Mauisaurus*, *Polycotylus*, &c.[3] According to the

[1] J. B. Hatcher, *Amer. Journ. Geol.* ix. (1900) p. 89. The huge Deinosaurs of the Argentine Republic (*Titanosaurus*, *Argyrosaurus*) have been described by Mr. Lydekker (*Ann. Mus. La Plata; Palæontologia Argentina*, Parts ii. and iii.). Mr. A. Smith Woodward has also named some small crocodiles (*Notosuchus*), an armoured chelonian (*Miolania*), and a snake, and has called attention to the remarkable mingling of ancient and modern types of animal life in the same collection, and to the remarkable resemblance between the Patagonian fauna and that of Australia, *Proc. Zool. Soc.* i. (1901), p. 169. The commingling of types may be partly due to inexact observation in the field and the confusion of strata of very different ages (see *postea*, p. 1244).

[2] R. L. Jack and R. Etheridge, jun., 'Geology of Queensland,' chaps. xxxi.-xxxiv.

[3] Etheridge, *Q. J. G. S.* xxviii. pp. 183, 340. Owen, *Geol. Mag.* vii. p. 49. Hector, *Trans. New Zealand Inst.* vi. p. 333. Haast, 'Geology of Canterbury and Westland,' p. 291. Hutton and Ulrich, 'Geology of Otago,' p. 44.

work of the Geological Survey Department of New Zealand, the Cretaceous system consists of a lower group (500 feet) of green and grey incoherent sandstones, in which beds of bituminous coal occur on the west coast (Lower Greensand), surmounted by a mass of strata (2000 to 5000 feet) which appears to connect the Cretaceous and Tertiary series. The upper part of the group (consisting of marls, greensand, limestone and chalk with flints) is thoroughly marine in origin, with *Ancyloceras*, *Belemnites*, *Rostellaria*, a plesiosaur, *Leiodon*, &c. The lower portion, which is capped by a black grit with marine fossils, contains the most valuable coal-deposits of New Zealand. The plants include dicotyledonous and coniferous forms closely allied to those still living in the country.[1]

PART IV. CAINOZOIC OR TERTIARY.

The close of the Mesozoic periods was marked in the west of Europe by great geographical changes, during which the floor of the Cretaceous sea was raised partly into land and partly into shallow marine and estuarine waters. These events must have occupied a vast period, so that, when sedimentation once more became continuous in the region, the organisms of Mesozoic time (save low forms of life) had, as a whole, disappeared and given place to others of a distinctly more modern type. In England, the interval between the Cretaceous and the next geological period represented there by sedimentary formations is marked by the abrupt line which separates the top of the Chalk from all later accumulations, and by the evidence that the Chalk seems to have been in some places extensively denuded before even the oldest of what are called the Tertiary formations were deposited upon its surface. There is evidently here a considerable gap in the geological record. We have no data for ascertaining what was the general march of events in the south of England between the eras chronicled respectively by the Upper Chalk and the overlying Thanet beds. So marked is this hiatus, that the belief was long prevalent that the close of Mesozoic time was marked by one of the great breaks in the geological history of the globe.

Here and there, however, in the Franco-Belgian basin, traces of some of the missing evidence are obtainable. We have seen that the Danian shelly and polyzoan limestones contain a mingling of true Cretaceous organisms with others which are characteristic of the older Tertiary formations. The fragmentary deposits in which this transition can be traced are interesting, in so far as they help to show that, though in western Europe there is, on the whole, a tolerably abrupt separation between Cretaceous and Tertiary deposits, there was nevertheless no real break between the two periods. The one merged insensibly into the other; but the strata which would have served as the chronicles of the intervening ages have either never been deposited in the area in question, or have since been in great measure destroyed. In southern Europe, especially in the south-eastern Alps, and probably in other parts of the Mediterranean basin, no sharp line can be drawn between Cretaceous and Eocene rocks. These deposits merge into each other in such a way as to show that the geographical changes of the western region did not extend

[1] Hector, 'Handbook of New Zealand,' 1883, p. 29.

into the south and south-east. In North America, also, on the one side, and in New Zealand on the other, there is a similar effacement of the hard and fast line which was once supposed to separate Mesozoic and Tertiary formations.

The name Tertiary, given in the early days of geology, before much was known regarding fossils and their history, has retained its hold on the literature of the science. It is often replaced by the terms "Cainozoic" (*recent life*) or "Neozoic" (*new life*), which express the great fact that it is in the series of strata comprised under these designations that most recent species and genera have their earliest representatives. Taking as the basis of classification the percentage of living species of mollusca found by Deshayes in the different groups of the Tertiary series, Lyell proposed a scheme of arrangement which has been generally adopted. The older Tertiary formations, in which the number of still living species of shells is very small, he named Eocene (*dawn of the recent*), including under that title those parts of the Tertiary series of the London and Paris basins wherein the proportion of existing species of shells was only $3\frac{1}{2}$ per cent.[1] The middle Tertiary beds in the valleys of the Loire, Garonne, and Dordogne, containing 17 per cent of living species, were termed Miocene (*less recent*), that is, containing a minority of recent forms. The younger Tertiary formations of Italy were included under the designation Pliocene (*more recent*), because they contained a majority, or from 36 to 95 per cent, of living species. This newest series, however, was further subdivided into Older Pliocene (35 to 50 per cent of living species) and Newer Pliocene (90 to 95 per cent). A still later group of deposits was termed Pleistocene (*most recent*), where the shells all belonged to living species, but the mammals were partly extinct forms. This classification, though somewhat artificial, has, with various modifications and amplifications, been adopted for the Tertiary groups, not of Europe only, but of the whole globe. The original percentages, however, often depending on local accidents, have not been very strictly adhered to. The most important modification of the terminology in Europe has been the insertion of another stage or group termed Oligocene (*few recent*), proposed by Beyrich, to include strata that were formerly classed partly as Upper Eocene and partly as Lower Miocene.[2]

[1] Some palæontologists, however, doubt whether any older Tertiary species, except of foraminifera or other lower organisms, is still living.

[2] Other divisions of the organic world have been proposed as the basis of a chronological arrangement of the Tertiary formations. Of these schemes the most important are those which have made use of the succession of the higher vertebrates as the groundwork of classification. Gaudry showed how the Tertiary formations of Europe were marked off from each other by the appearance and disappearance of successive types of mammalian life ('Les Enchaînements du Monde Animal—Mammifères Tertiaires,' 1878). Boyd Dawkins proposed the fossil mammalia as the basis of a stratigraphical arrangement (*Q. J. G. S.* 1880, p. 379). Dr. Forsyth Major has elaborated a table of the succession of mammalian genera from the Trias to the top of the Lower Pliocene (*Geol. Mag.* 1899, pp. 60-69). Marsh employed not only mammalian types but the remarkable reptilian forms supplied by the Mesozoic and Cainozoic rocks of the United States, and he in some cases named a formation or group of strata from its most characteristic vertebrate, as in the case of

Some writers, recognising a broad distinction between the older and the younger Tertiary deposits of Europe, have proposed a classification into two main groups: 1st, Eocene, Older Tertiary or Palæogene, including Eocene and Oligocene; and, 2nd, Younger Tertiary or Neogene, comprising Miocene and Pliocene. This subdivision has been advocated on the ground that, while the older deposits indicate a tropical climate, and contain only a very few living species of organisms, the younger groups point to a climate approaching more and more to that of the existing Mediterranean basin, while the majority of their fossils belong to living species.[1]

The Tertiary periods witnessed the development of the present distribution of land and sea and the final upheaval of most of the great mountain-chains of the globe, Some of the most colossal disturbances of the terrestrial crust, of which any record remains, took place during these periods. Not only was the floor of the Cretaceous sea upraised into low lands, with lagoons, estuaries, and lakes, but afterwards, throughout the heart of the Old World, from the Pyrenees to Japan, the bed of the early Tertiary or nummulitic sea was upheaved into a succession of giant mountains, some portions of that sea-floor now standing at a height of at least 16,500 feet above the sea.

During Tertiary time also there was an abundant manifestation of volcanic activity. After a long quiescence during the succession of Mesozoic periods, volcanoes broke forth with great vigour both in the Old and the New World. Vast floods of lava were poured out, and a copious variety of rocks was produced, ranging from highly basic basalts, limburgites, and peridotites to rhyolites, quartz-felsites, and granites.

The rocks deposited during these periods are distinguished from those of earlier times by increasingly local characters. The nummulitic limestone of the older Tertiary groups is indeed the only widespread massive formation which, in the uniformity of its lithological and palæontological characters, rivals the rocks of Mesozoic and Palæozoic time. As a rule, the Tertiary deposits now visible as part of the dry land are loose and incoherent, and present such local variations, alike in their mineral composition and organic contents, as to show that they were mainly accumulated in detached basins of comparatively limited extent, and in seas so shallow as to be apt from time to time to be filled up or elevated, and to become in consequence brackish or even fresh.[2] These local characters are increasingly developed in proportion to the recentness of the deposits. The pelagic accumulations of Tertiary time

"Atlantosaurus Beds," "Ceratops Beds," "Brontotherium Beds," "Pliohippus Beds" (*Amer. Journ. Sci.* xiv. (1877), pp. 338-378; vi. (1898), p. 483; *Geol. Mag.* 1898, p. 565). The same principle has been carried out with greater precision by Messrs. Osborn, Wortman, and Matthew, who have prepared a table of the succession of formations in the whole Tertiary series of the West, and have placed opposite to each subdivision the name of the vertebrate fossil by which it is more particularly characterised (*Bull. Amer. Mus. Nat. Hist.* xii. (1899), p. 20).

[1] Hörnes, *Jahrb. Geol. Reichsanst.* 1864, p. 510.

[2] The peculiar characters of the Tertiary rocks of the Western Territories of North America are, however, displayed over areas which in Europe would be regarded as enormous.

still for the most part lie beneath the oceans in which they were laid down, though here and there, as in the Pacific basin, upheaval connected with volcanic action has raised some parts of the limestones above sea-level (*ante*, p. 621).

Climate during Tertiary time underwent in the northern hemisphere some remarkable changes. Judging from the terrestrial vegetation preserved in the strata, we may infer that in England the climate of the oldest Tertiary periods was of a temperate character,[1] but that it became during Eocene time tropical and subtropical, even in the centre of Europe and North America. It then gradually grew more temperate, but flowering plants and shrubs continued to live even far within the Arctic circle, where, then as now, unless the axis of the earth has meanwhile shifted, there must have been six sunless months every year. Growing still cooler, the climate passed eventually into a phase of extreme cold, when snow and ice extended from the Arctic regions far south into Europe and North America. Since that time, the cold has again diminished, until the present thermal distribution has been reached.

With such changes of geography and climate, the plant and animal life of Tertiary time, as might have been anticipated, is found to have been remarkably varied. Entering upon the Tertiary series of formations, we find ourselves upon the threshold of the modern types of life. The ages when lycopods, ferns, cycads, and yew-like conifers were the leading forms of vegetation, have passed away, and that of the dicotyledonous angiosperms—the hard-wood trees and evergreens of to-day—now succeeds them, but not by any sudden extinction and re-creation; for, as we have seen (p. 1164), some of these trees had already made their appearance in Cretaceous times both in the Old and New Worlds. The hippurites, inocerami, ammonites, belemnites, baculites, turrilites, scaphites, and other mollusks, which had played so large a part in the molluscan life of the later Secondary periods, now cease. The great reptiles, too, which, in such wonderful variety—deinosaurs, ichthyosaurs, plesiosaurs, pterosaurs, and other types—had been the dominant animals of the earth's surface, alike on land and sea, ever since the commencement of the Lias, now vanished. On the other hand, the mammalia advanced in augmenting diversity of type until they reached a maximum in variety of form and in bulk just before the cold epoch referred to. When that refrigeration passed away and the climate became milder, the extraordinary development of mammalian life that preceded it is found to have disappeared also, being only feebly represented in the living fauna at the head of which man has taken his place.

[1] J. S. Gardner in "Geology of the Isle of Wight," *Mem. Geol. Surv.* 1889, p. 106. In the detailed discussion of the climate of Eocene time by Max Semper (cited *ante*, p. 834), he analyses the evidence furnished by the published lists (sometimes now of little critical value) of older Tertiary plants and invertebrates, discusses the probable direction and temperature of the marine currents of the period, and concludes that geographical changes have had far more influence on climate than has generally been assumed. He considers the effect of a displacement of the north pole about 20° towards North America.

Section i. Eocene.

§ 1. General Characters.

ROCKS.—In Europe and Asia the most widely distributed deposit of this epoch is the nummulitic limestone, which extends from the Pyrenees through the Alps, Carpathians, Caucasus, Asia Minor, Northern Africa, Persia, Beloochistan, and the Suleiman Mountains, and is found in China and Japan. It attains a thickness of several thousand feet. In some places it is composed mainly of foraminifera (*Nummulites* and other genera); but it sometimes includes a tolerably abundant marine fauna. Here and there it has assumed a compact crystalline marble-like structure, and can then hardly be distinguished from a Mesozoic or even Palæozoic rock. Enormous masses of sandstone occur in the eastern Alps (Vienna sandstone, Flysch), referred partly to the same age, but seldom containing any fossils save fucoids (pp. 1205, 1239). The most familar European type of Eocene deposits, however, is that of the Anglo-Parisian and Franco-Belgian area, where are found numerous thin local beds of usually soft and uncompacted clay, marl, sand, and sandstone, with hard and soft bands of limestone, containing alternations of marine, brackish, and fresh-water strata. This type of sedimentation evidently indicates more local and shallower basins of deposit than the wide Mediterranean sea, which stretched across the heart of the Old World in early Tertiary time.

On the western side of the Atlantic the familiar European type of soft clays and sands emerges along the coast of the United States as a belt which, beginning in New Jersey, broadens out southwards so as to cover all Florida, to sweep over the plains around the Gulf of Mexico, and to stretch up the valley of the Mississippi into Missouri. As the rocks are traced round the Gulf region they are found to have become firm sandstones, shales, and limestones, with seams of lignite. In the interior a succession of large fresh-water lakes was formed, wherein a series of sediments was accumulated unconformably upon the Cretaceous formations. These deposits have preserved with remarkable fulness a record of the plant and animal life of the time. On the Pacific slope the Eocene sea extended for some way inland over the site of California, Oregon, and Washington.

LIFE.—The flora of Eocene time has been abundantly preserved on certain horizons. In the English Eocene groups, a succession of several distinct floras has been observed, those of the London Clay and Bagshot beds being particularly rich. The plants from the London Clay indicate a warm climate.[1] They include species of *Callitris*, *Solenostrobus*, *Cupressinites*, *Sequoia*, *Ginkgo* (*Salisburia*), *Agave*, *Smilax*, *Amomum*, *Nipa* (Fig. 460), *Magnolia*, *Nelumbium*, *Victoria*, *Hightea*, *Sapindus*, *Eucalyptus*, *Cotoneaster*, *Prunus*, *Amygdalus*, *Faboidea*, &c. Proteaceous plants like the living

[1] Ettingshausen, *Proc. Roy. Soc.* xxix. (1879), p. 388.

Australian *Petrophila* and *Isopogon* have been asserted to form part of the Lower Eocene vegetation, but their occurrence is not yet proved; the so-called *Petrophiloides* is now regarded as an alder (Fig. 460).[1] During Middle Eocene time in the umbrageous forests of evergreen trees

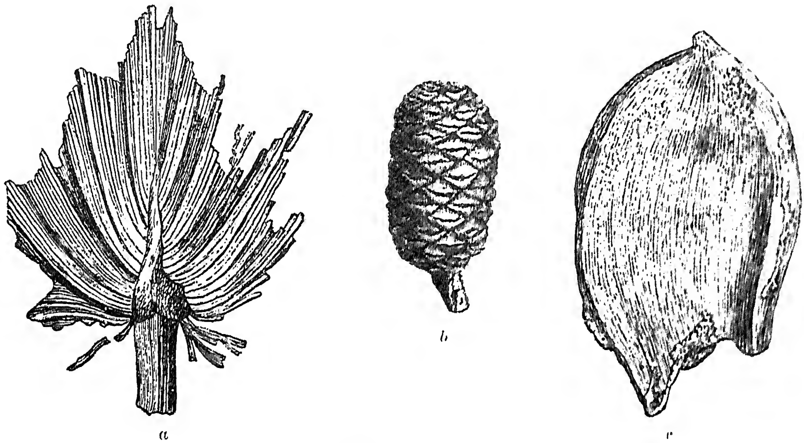

Fig. 460.—Eocene Plants.
a, Sabal oxyrhachis, Heer (reduced); *b*, Petrophiloides Richardsoni; *c*, Nipa Burtini, Brongn, sp. ($\frac{1}{2}$).

—laurels, cypresses, and yews—there grew species of ferns (*Lygodium*, *Asplenium*, &c.), also of many of our familiar trees besides those just mentioned, such as chestnuts, beeches, elms, poplars, hornbeams, willows, figs, planes, and maples. The subtropical character of the climate was

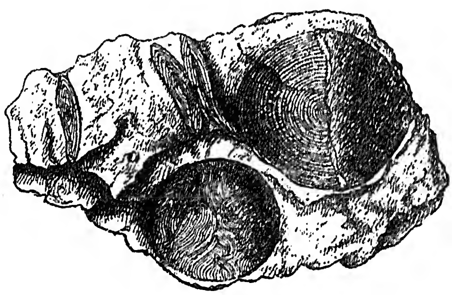

Fig. 461.—Nummulitic Limestone ($\frac{2}{3}$).

shown by clumps of Pandanus, with here and there a fan-palm (Fig. 460) or feather-palm, a tall aroid or a towering cactus.[2]

[1] J. S. Gardner, *op. cit.* p. 108.

[2] J. S. Gardner and C. B. Ettingshausen, "British Eocene Flora," 2 vols. *Palæontograph. Soc.* 1879-86; L. Crié, "Recherches sur la Végétation de l'Ouest de la France à l'Epoque Tertiaire," *Ann. Scien. Géol.* ix. (1877); Ettingshausen, *Proc. Roy. Soc.* xxx. (1880), p. 228; Comte de Saporta, 'Le Monde des Plantes,' 1879, p. 207.

The Eocene fauna of western and central Europe presents similar

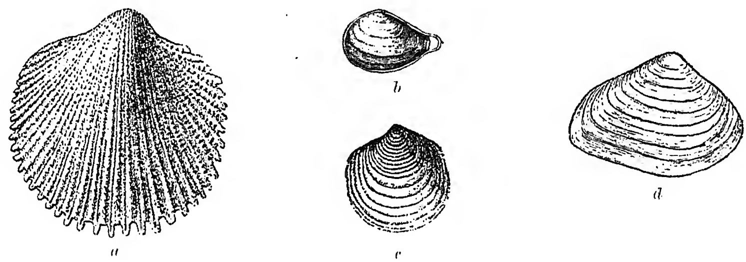

Fig. 462.—Eocene Lamellibranchs.
a, Cardium porulosum, Lam.; *b*, Corbula regulbiensis, Mor.; *c*, Lucina squamula, Desh.; *d*, Corbicula (Cyrena) cuneiformis, Sow. (⅔).

evidence of tropical or subtropical conditions. Especially characteristic are foraminifera of the genus *Nummulites*, which occur in prodigious numbers

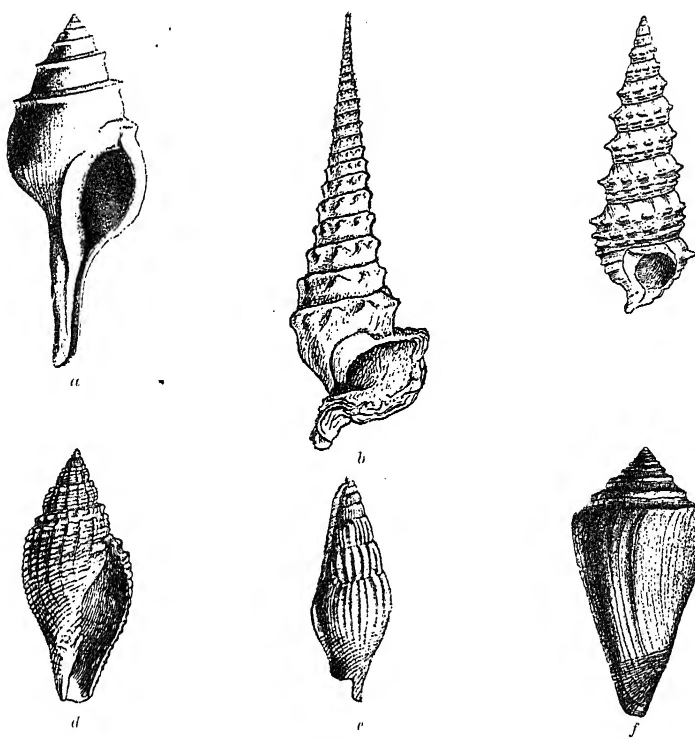

Fig. 463.—Eocene Gasteropods.
a, Fusus (Clavalithes) longævus, Brand. (⅔); *b*, Cerithium (Campanile) giganteum, Lam. ($\frac{1}{10}$); *c*, Melania (Melanatria) inquinata, Defr. (⅔); *d*, Volutilithes elevata, Sow. (⅔); *e*, Rimella fissurella, Desh. (⅔); *f*, Conus deperditus, Brug. (½).

in the nummulite limestone (Fig. 461), and also occupy different horizons

in the English and French Eocene basins. The assemblage of mollusca is very large, most of the genera being still living, though many of them are confined to the warmer seas of the globe (Figs. 462, 463). Characteristic forms are *Belosepia*, *Nautilus*, *Cancellaria*, *Fusus*, *Pseudoliva*, *Oliva*, *Voluta*, *Conus*, *Mitra*, *Cerithium*, *Melania*, *Turritella*, *Rostellaria*, *Pleurotoma*, *Cypræa*, *Natica*, *Scala*, *Corbula*, *Cyrena*, *Cytherea* (*Meretrix*), *Chama*, *Lucina*.[1] Fish remains are not infrequent in some of the clays, chiefly as scattered teeth (Fig. 464) and otoliths. The living tropical siluroid genus *Arius* has been found in these deposits. Some of the more common selachian genera are *Lamna*, *Odontaspis*, *Myliobatis*, *Aetobatis*, *Pristis*. Ganoids are now rare. Teleosteans are represented by *Phyllodus*, *Arius*, and other genera. The Eocene reptiles present a singular contrast to those of Mesozoic time. They consist largely of tortoises and turtles, with crocodiles and sea-snakes. It is suggestive to find remains of siluroid fish, crocodiles, and chelonians, preserved in deposits of Eocene age, for the assemblage is like what may now be met with in tropical seas of the

a

Fig. 464. Eocene Fishes.
a, Odontaspis elegans, tooth of, Az. ([illegible]); *b*, Lamna obliqua, tooth of, Az. ([illegible])

present time. An interesting series of remains of birds has been obtained from the English Eocene beds. These include *Argillornis longipennis* (perhaps representative of, but larger than, the modern albatross), *Dasornis*, *Gastornis*, *Halcyornis toliapicus*, *Lithornis vulturinus*, and *Odontopteryx toliapicus*, a fish-eating bird with bony tooth-like processes to its large beak. From the upper Eocene beds of the Paris basin ten species of birds have been obtained, including forms allied to the buzzard, osprey, hawk, nuthatch, quail, pelican, ibis, flamingo, and African hornbill.[2] But the most notable feature in the palæontology of the period is the advent of some of the numerous mammalian forms for which Tertiary time was so distinguished. In the Lower Eocene period appeared the primitive carnivores *Arctocyon* and *Palæonictis*, two animals with marsupial affinities, the former with bear-like teeth, the latter with

[1] For a list of British Eocene and Oligocene mollusca consult the volume by R. B. Newton, one of the series of Catalogues issued by the British Museum.

[2] Owen, *Q. J. G. S.* 1856, 1873, 1878, 1880. Boyd Dawkins, 'Early Man in Britain,' p. 33. Milne Edwards, 'Oiseaux Fossiles,' ii. 543.

teeth like those of the Tasmanian dasyure; also the tapir-like *Coryphodon*; the small hog-like *Hyracotherium*, with canine teeth like those of the peccary, and a shape intermediate between that of the hog and the hyrax. Middle Eocene time was distinguished by the advent of a group of remarkable tapir-like animals (*Palæotherium*, *Palaplotherium*, *Lophiodon*,[1] *Pachynolophus*); creodonts or forms of primitive carnivores (*Proviverra*, *Pterodon*, *Hyænodon*, *Cynodon*); and lemuroids (*Heterohyus*, *Microchœrus*, *Cœnopithecus*), the earliest representatives of the tribe of monkeys. With the upper Eocene period, besides the abundant older tapir-like forms, there came others (*Anoplotherium* (Fig. 468), *Anchitherium*), some of which presented characters intermediate between those of the tapiroid Palæotheres and the true Equidæ. They were about the size of small

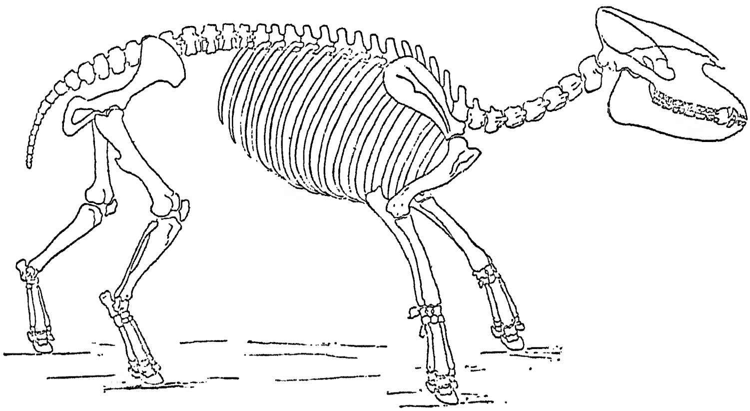

Fig. 465.—Palæotherium magnum, Cuv. ($\frac{1}{25}$).

ponies, had three toes on each foot, and are regarded as ancestors of the horse. Numerous hog-like animals (*Diplopus*, *Hyopotamus*) mingled with herds of ancestral hornless forms of deer and antelopes (*Dichobune*, *Dichodon*, *Amphitragulus*). Opossums abounded. Among the carnivores above referred to were animals resembling wolves (*Cynodon*), foxes (*Amphicyon*), and wolverines (*Hyænodon* or *Tylodon*). There appear to have been also representatives of our hedgehogs, squirrels, and bats.[2]

It is from the thick Eocene lacustrine formations of the western Territories of the United States that the most important additions to our knowledge of the animals of early Tertiary time have been made, thanks to the admirable and untiring labours, first of Leidy, subsequently of Marsh at Newhaven, Cope at Philadelphia, and Osborn and Wortman in New York. The herbivorous ungulates appear to have formed a chief element in this western fauna. They included some of the oldest known ancestors of the horse, with four-toed feet, and even in one form

[1] H. Filhol, *Mem. Géol. Soc. France* (3), v. No. 1 (1888).

[2] Gaudry, 'Les Enchaînements du Monde Animal,' p. 4. Boyd Dawkins, 'Early Man in Britain,' chap. ii. L. Rütimeyer, *Verhandl. Naturfor. Basel.* ix. (1890), Heft 2.

(*Eohippus*) with rudiments of a fifth toe; also various hog-like animals *Eohyus*, *Parahyus*), tapirs, and rhinoceroses. Some of the most peculiar

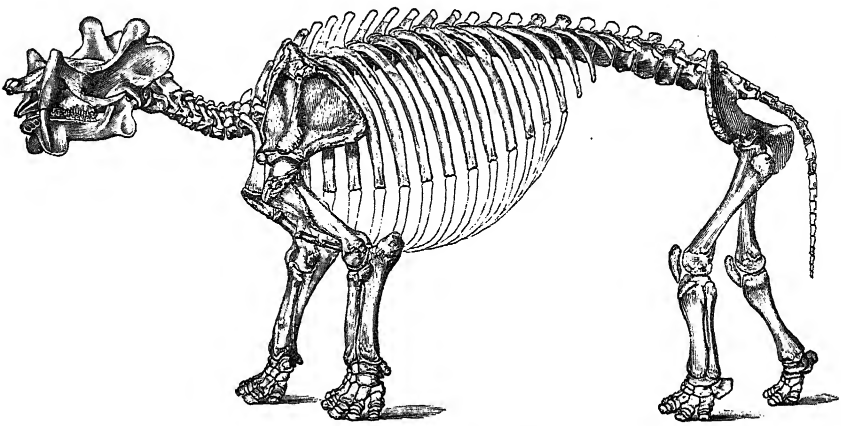

Fig. 466.—Uintatherium mirabile, Marsh ($\frac{1}{30}$).

forms were those of the type termed Tillodont by Marsh, presenting a remarkable union of the characters of ungulates, rodents, and carnivores,

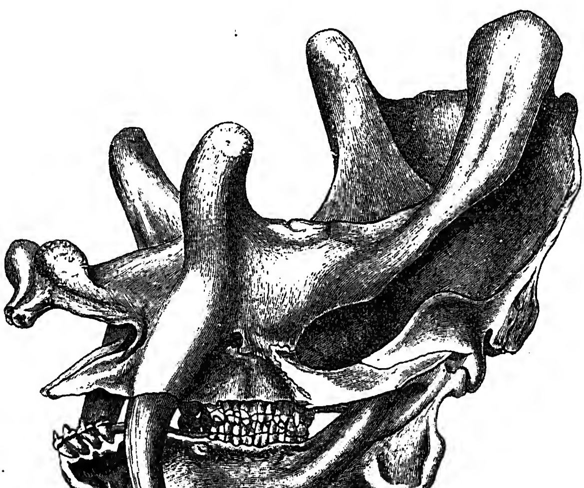

Fig. 467.—Skull of Uintatherium (Tinoceras) ingens (about $\frac{1}{11}$).

and especially striking from their pair of long incisor teeth (*Tillotherium*, *Anchippodus*, *Stylinodon*). This author, from another assemblage of

skulls and bones of animals about as large as a fox, has proposed to establish a separate order of mammals, that of the Mesodactyla, which in his opinion stands in somewhat the same relation to the typical ungulates that the tillodonts do to rodents.[1] Still more extraordinary were the Deinocerata or Uintatheriidæ, possessing, according to Marsh, the size of elephants, with the habit of rhinoceroses, but bearing a pair of long horn-like prominences on the snout, another pair on the forehead, and a single one on each cheek (*Uintatherium*, Figs. 466,[2] 467, including in the same genus the forms described under the names *Deinoceras*, *Tinoceras*, *Eobasileus*, *Loxolophodon*). With these animals there coexisted large and small carnivores of the primitive type of the Creodonts (*Palæonictis*, *Viverravus*, *Amblyctonus*, *Patriofelis*, *Oxyæna*, *Miacis* (*Uintacyon*), *Sinopa*, *Pachyæna*, &c.). There were likewise early types of lemuroid monkeys (*Anaptomorphus*) and others which by some palæontologists have been regarded as probably primitive anthropoid apes (*Microsyops*).

§ 2. Local Development.

Britain.[3] Entirely confined to the south-eastern part of England,[4] the British Eocene strata occupy two synclinal depressions in the Chalk, which, owing to denudation, have become detached into the two well-defined basins of London and Hampshire. They have been arranged as in the subjoined table:—

	Hampshire.	*London.*
Upper	Headon Hill or Barton Sands. Barton Clay.	Upper Bagshot Sands.
Middle	Bracklesham beds, and leaf beds of Bournemouth and Alum Bay.	Middle Bagshot beds, part of Lower Bagshot Sands.
Lower	London Clay (Bognor beds). Woolwich and Reading beds.	Part of Lower Bagshot Sands. London Clay. Blackheath or Oldhaven beds. Woolwich and Reading beds. Thanet Sand.

LOWER EOCENE.—The Thanet Sand[5] at the base of the London basin consists of pale yellow and greenish sands, sometimes clayey, and containing at their bottom a thin, but remarkably constant, layer of green-coated flints resting directly on the Chalk. According to Mr. Whitaker, it is doubtful if proof of actual erosion of the Chalk can anywhere be seen under the Tertiary deposits in England, and he states that the

[1] Marsh, *op. cit.* (1892), p. 445. See also H. F. Osborn, *Journ. Acad. Philadelph.* ix. (1888). Compare the lists of mammalia, *postea*, pp. 1234 and 1243.

[2] This restoration was supplied by Professor Marsh, whose Monograph on the Deinocerata the student should consult. *Mon. U.S. G. S.* vol. x. (1886).

[3] See Conybeare and Phillips, 'Geology of England and Wales.' Prestwich, *Q. J. G. S.* vols. iii. vi. viii. x. xi. xiii. Edward Forbes, "Tertiary Fluvio-marine Formation of the Isle of Wight," *Mem. Geol. Surv.* 1856. H. W. Bristow, C. Reid, and A. Strahan, "Geology of the Isle of Wight," *Mem. Geol. Surv.* 2nd edit. 1889. Whitaker, "Geology of London," *Mem. Geol. Surv.* 1889. Phillips, 'Geology of Oxford and the Thames Valley,' 1871.

[4] Mr. J. S. Gardner, however, has classed as Eocene the plant-bearing beds of Bovey, Antrim, &c., described at p. 1251 under the Oligocene subdivision.

[5] Prestwich, *Q. J. G. S.* viii. (1852), p. 237.

Thanet Sand everywhere lies upon an even surface of Chalk with no visible unconformability.[1] Professor Phillips, on the other hand, describes the Chalk at Reading as having been "literally ground down to a plane or undulated surface, as it is this day on some parts of the Yorkshire coast," and having likewise been abundantly bored by lithodomous shells.[2] The Thanet Sand appears to have been formed only in the London basin; at least it has not been recognised at the base of the Eocene series in Hampshire. It has yielded numerous organic remains in East Kent, but is almost unfossiliferous farther west. Its fossils comprise about 70 known species (all marine except a few fragments of terrestrial vegetation). Among them are several foraminifera, numerous lamellibranchs (*Astarte tenera*, *Cyprina scutellaria* (*planata*), *Ostrea bellovacina*, *Cucullæa decussata* (*crassatina*), *Pholadomya cuneata*, *P. Koninckii*, *Corbula regulbiensis*, &c.), a few species of gasteropods (*Natica infundibulum* (*subdepressa*), *Aporrhais Sowerbii*, &c.), a nautilus, and the teeth, scales, and bones of fishes (*Odontaspis*, *Pisodus*).

The Woolwich and Reading Beds,[3] or "Plastic Clay" of the older geologists, consist of lenticular sheets of plastic clay, loam, sand, and pebble-beds, so variable in character and thickness over the Tertiary districts that their homotaxial relations would not at first be suspected. One type (Reading) presenting unfossiliferous lenticular, mottled, bright-coloured clays, with sands, sometimes gravels, and even sandstones and conglomerates, occurs throughout the Hampshire basin and in the northern and western part of the London basin. A second type (Woolwich), found in West Kent, Surrey, and Sussex, from Newhaven to Portslade, consists of light-coloured sands and grey clays, crowded with estuarine shells. A third type, seen in East Kent, is composed only of sands containing marine fossils. These differences in lithological and palæontological characters serve to indicate the geographical features of the south-east of England at the time of deposit, showing in particular that the sea of the Thanet beds had gradually shallowed, and that an estuary now partly extended over its site. The organic remains as yet obtained from this group amount to more than ·100 species. They include a few plants of terrestrial growth, such as *Ficus Forbesi*, *Grevillea Heeri*, *Laurus Hookeri*, *Aralia*, *Lygodium*, *Liriodendron*, and *Platanus*—a flora which, containing some apparently persistent types, has a temperate facies.[4] The lamellibranchs are partly estuarine or fresh-water, partly marine; characteristic species being *Corbicula cuneiformis*, *C. cordata*, and *C. tellinella*. *Ostrea bellovacina* forms a thick oyster-bed at the base of the series, besides occurring throughout the group. *Ostrea tenera* is likewise abundant. The gasteropods include a similar mixture of marine with fluviatile species (*Potamides funatus*, *Melania* (*Melanatria*) *inquinata*, *Melanopsis buccinoides*, *Neritina globulus*, *Natica infundibulum*, *Pisania* (*Fusus*) *lata*, *Viviparus* (*Paludina*) *lentus*, *Planorbis hemistoma*, *Pitharella Rickmanni*, &c.). The fish are chiefly sharks (*Odontaspis*). Bones of turtles, scutes of crocodiles, and remains of gigantic birds (*Gastornis*) have been found. The highest organisms are bones of mammalia, including the *Coryphodon*.

The Blackheath or Oldhaven Beds,[5] at the base of the London Clay, consist in W. Kent almost wholly of rolled flint-pebbles in a sandy base, which, as Mr. Whitaker suggests, may have accumulated as a bank at some little distance from shore. Though of trifling thickness (20-40 feet), they have yielded upwards of 150 species of fossils. Traces of *Ficus*, *Cinnamomum*, and conifers have been obtained from them, indicating perhaps a more subtropical character than the flora of the beds below,

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1 'Geology of London,' p. 107.

2 'Geology of Oxford,' p. 442.

3 Prestwich, *Q. J. G. S.* x. p. 75; Whitaker, 'Geology of London,' p. 222.

4 C. B. Ettingshausen and J. S. Gardner, "British Eocene Flora," *Palæontog. Soc.* vol. i. (1879), p. 29.

5 Whitaker, *Q. J. G. S.* xxii. (1866), p. 412; 'Geology of London,' p. 214.

but without the Australian and American types which appear in so marked a manner in the later Eocene floras.[1] The organisms, however, are chiefly marine and partly estuarine shells, the gasteropods being particularly abundant (*Calyptræa aperta* (*trochiformis*), *Potamides funatus*, *Melania* (*Melanatria*) *inquinata*, *Natica infundibulum*, *Protocardia plumstediensis*, *Pectunculus terebratularis*, &c.).

The London Clay[2] is a deposit of stiff brown and bluish-grey clay, with layers of septarian nodules of argillaceous limestone. Its bottom beds, commonly consisting of green and yellow sands, and rounded flint-pebbles, sometimes bound by a calcareous cement into hard tabular masses, form in the London basin a well-marked horizon. The London Clay is typically developed in that basin, attaining its maximum thickness (500 feet) in the south of Essex. Its representative in the Hampshire basin, known as the "Bognor Beds," and exposed at Bognor on the Sussex coast and at Portsmouth, consists of clays, sands, and calcareous sandstones, thus differing somewhat, both lithologically and palæontologically, from the typical development in the London basin. The London Clay has yielded a long and varied suite of organic remains, that point to its having been laid down in the sea beyond the mouth of a large estuary, into which relics of the vegetation, and even sometimes of the fauna, of the adjacent land were swept. According to Professor T. Rupert Jones, the depth of the sea, as indicated by the foraminifera of the deposit, may have been about 600 feet. Professor Prestwich has pointed out that there are traces of the existence of palæontological zones in the clay, the lowest zone indicating, in the east of the area of deposit, a maximum depth of water, while a progressive shallowing is shown by three higher zones, the uppermost of which contains the greater part of the terrestrial vegetation, and also most of the fish and reptilian remains. The fossils are mainly marine mollusca, which, taken in connection with the flora, indicate that the climate was somewhat tropical in character. The plants include the fruits, seeds, or leaves of the following, among other genera, the fossils having been mostly obtained from the Isle of Sheppey: *Sequoia*, *Pinus*, *Callitris*, *Ginkgo*; *Musa*, *Nipa*, *Sabal*, *Chamærops*; *Quercus*, *Liquidambar*, *Laurus*, *Nyssa*, *Diospyros*, *Symplocos*, *Magnolia*, *Victoria*, *Hightea*, *Sapindus*, *Cupania*, *Eugenia*, *Eucalyptus*, *Amygdalus*.[3] Diatoms are found in the lower 50 feet of the London Clay,[4] and numerous foraminifera have been obtained by washing the clay. Crustacea abound (*Xanthopsis*, *Hoploparia*). Of the lamellibranchs some of the most usual genera are *Avicula*, *Cardium*, *Corbula*, *Nuculana* (*Leda*), *Modiola*, *Nucula*, *Pholadomya*, *Pinna*, and *Venericardia*. Gasteropods are the prevalent mollusks, the common genera being *Pleurotoma* (45 species), *Fusus* (15 species), *Cypræa*, *Murex*, *Natica*, *Cassis* (*Cassidaria*), *Pyrula*, and *Voluta*. The cephalopods are represented by 6 or more species of *Nautilus*, by *Beloscpia sepioidea*, and *Beloptera Levesquei*. Nearly 100 species of fishes occur in this formation, the rays (*Myliobatis*, 14 species) and sharks (*Odontaspis*, *Lamna*, &c.) being specially numerous. A sword-fish (*Tetrapterus priscus*) and a saw-fish (*Pristis*) have likewise been met with. The reptiles were numerous, and markedly unlike, as a whole, to those of Secondary times. Among them are numerous turtles and tortoises (*Lytoloma*, 3 species, *Argillochelys*, 2 species, *Trionyx*, 1 species, *Podocnemys*, 2 species, *Pseudotrionyx*, 1 species), two species of crocodile, and a sea-snake (*Palæophis toliapicus*), estimated to have equalled in size a living *Boa constrictor*. The London clay has yielded the birds above mentioned (*Lithornis vulturinus*, *Halcyornis toliapicus*, *Dasornis londinensis*, *Odontopteryx toliapicus*, *Argillornis longipennis*). The mammals included forms resembling the tapirs (*Hyracotherium*, *Coryphodon*, &c.), an opossum (*Didelphys*), and a bat. The carcases

[1] J. S. Gardner, *op. cit.* pp. 2, 10.

[2] Prestwich, *Q. J. G. S.* vi. p. 255; x. p. 435; Whitaker, 'Geology of London,' p. 238.

[3] Ettingshausen and Gardner, "British Eocene Flora," *Palæontograph. Soc.* p. 12; Ettingshausen, *Proc. Roy. Soc.* xxix. (1879).

[4] W. H. Shrubsole, *Journ. Roy. Microscop. Soc.* 1881.

of these animals must have been borne seawards by the great river which transported so much of the vegetation of the neighbouring land.

Middle Eocene.—In the London basin this division consists chiefly of sands, which are comprised in the two sub-stages of the lower and middle "Bagshot Beds." The lower of these, consisting of yellow, siliceous, unfossiliferous sands, with irregular light clayey beds, attains a thickness of about 100 to 150 feet. The second sub-stage, or "Middle Bagshot Beds," is made up of sands and clays, sometimes 50 or 60 feet thick, containing few organic remains, among which are bones of turtles and sharks, with a few mollusks (*Venericardia acuticosta, V. elegans, V. planicosta, V. imbricata, Corbula gallica, C. Lamarckii, Ostrea flabellula*).

In the Hampshire basin, the Middle Eocene series attains a much greater development, being not less than 660 feet thick at the west end of the Isle of Wight, where it consists of variously-coloured unfossiliferous sands and clays, with minor beds of iron-stone and plant-bearing clays, pointing to an alternation of marine and estuarine conditions of deposit.[1] On the mainland at Studland, Poole, and Bournemouth, the same strata appear. The important series of clays, marls, sands, and lignites, upwards of 100 feet thick, known as the Bracklesham beds from their occurrence at Bracklesham, on the coast of Sussex, has yielded a large series of marine organisms. Among these are the fishes *Pristis, Odontaspis, Lamna, Myliobatis*, also the sea-snake *Palæophis*, and the mollusks *Belosepia sepioidea, B. Owenii, Cypræa inflata, Gisortia tuberculosa, Marginella eburnea, M. ovulata, Voluta angusta, V. muricina, Volutilithes crenulatus, V. spinosus, V. cithara, Lyria Branderi, Mitra labratula, Conus deperditus, C. Lamarckii, Pleurotoma dentata, P. textiliosa, Murex (Pteronotus) asper, Clavalithes (Fusus) longævus, Turritella imbricataria, Ostrea dorsata, O. flabellula, Pecten (Pseud-amusium) corneus, P. (Amusium) squamula, Lima expansa, Spondylus rarispina, Avicula media, Pinna margaritacea, Modiola (Lithodomus?) Deshayesi, Arca biangula (Branderi), A. interrupta, A. planicosta, Limopsis granulata, Nucula minor, Nuculana (Leda) galeottiana, Venericardia acuticosta, V. elegans, V. imbricata, V. planicosta, Crassatella grignonensis, Chama calcarata, C. gigas, Nummulites lævigatus, (N. scaber) Alveolina fusiformis.*[2] The Bracklesham beds reappear to a small extent, as greenish clayey sands, in the London basin, where they form part of the Middle Bagshot group.

One of the most characteristic features of the English Middle Eocene division is the abundant terrestrial flora which has been disinterred especially from the plant-beds of Alum Bay and Bournemouth. It is remarkable that this vegetation is apt to occur in patches or "pockets" which may mark the sites of pools into which it was blown by wind or transported by streams, so that varied though it be, it doubtless affords no adequate picture of the variety of the flora from which it was derived. From Alum Bay, in the Isle of Wight, according to Ettingshausen's census, not fewer than 116 genera and 274 species belonging to 63 families have been obtained.[3] A feature of special interest in this flora is to be found in the fact that it is the most tropical in general aspect which has yet been studied in the northern hemisphere. This character is particularly indicated by the numbers of species of fig, and by the Artocarpeæ, Cinchonaceæ, Sapotaceæ, Ebenaceæ, Büttneriaceæ, Bombaceæ, Sapindaceæ, Malpighiaceæ, &c. The most conspicuous and typical forms are *Ficus Bowerbankii, Aralia primigenia, Dryandra acutiloba, D. Bunburyi, Cassia Ungeri*, and the fruits of *Cæsalpinia*. Many of the dicotyledons belong to species elsewhere found in what have been considered to be Miocene deposits. More than fifty species of the Alum Bay flora are found also in those of Sotzka and

[1] "Geology of the Isle of Wight" in *Mem. Geol. Surv.* p 109.

[2] See Dixon's 'Geology of Sussex'; Edwards and S. Wood, "Monograph of Eocene Mollusca," *Palæontograph. Soc.*

[3] Mr. Gardner suspects that in this estimate species from other localities have been included with those from Alum Bay, "Geology of the Isle of Wight" in *Mem. Geol. Surv.* p. 105.

Häring (p. 1239), while a lesser number occur in those of Sézanne (p. 1235) and the Lignitic series of Western America.[1] The Bournemouth beds, believed to be rather higher in the series than those of Alum Bay, lie immediately below the Bracklesham beds. They have yielded none of the prevailing types of plants that occur at Alum Bay, but this may no doubt be due to local accidents of deposition. The Bournemouth flora is likewise an abundant one, and suggests a comparison of its climate and forests with those of the Malay archipelago and tropical America.[2] The celebrated lignitiferous deposit of Bovey Tracey in Devonshire, as already mentioned, has been referred by Mr. Gardner to this horizon.[3] Crocodiles still haunted the waters, for their bones are mingled with those of sea-snakes and turtles, and with tapiroid and other older Tertiary types of terrestrial creatures. The occurrence of the foraminiferal genus *Nummulites* is noteworthy. Though not common in England, it abounds, as already stated, in the Eocene deposits of central and eastern Europe.

UPPER EOCENE.—The highest division of the Eocene strata of England, according to the classification here followed, includes the uppermost part of the Hampshire series, which has long been known as the "Barton Clay," with, perhaps, the Upper Bagshot Sand of the London Basin. The Barton Clay does not occur in that basin, but forms an important feature in Hampshire, where, on the cliffs of Hordwell, Barton, and in the Isle of Wight, it attains a thickness of 300 feet. It consists of grey, greenish and brown clays, with bands of sand, and has long been well known for the abundance and excellent preservation of its fossils, chiefly mollusks, of which more than 500 species have been collected, but including also fishes (*Lamna*, *Myliobatis*, *Arius*) and a crocodile (*Diplocynodon*). The following list includes some of the more important species for purposes of comparison with equivalent foreign deposits: *Volutilithes luctatrix*, *V. ambiguus*, *V. athleta*, *Conus scabriculus*, *Conorbis dormitor*, *Pleurotoma rostrata* (and numerous other species), *Clavalithes* (*Fusus*) *longævus*, *Sycum pyrus*, *Ostrea gigantea*, *O. flabellula*, *Vulsella deperdita*, *Pecten reconditus*, *Lima compta*, *L. soror*, *Avicula media*, *Modiola* (*Modiolaria*) *seminuda*, *M.* (*Modiolaria*) *sulcata*, *M. tenuistriata*, *Arca appendiculata*, *Pectunculus* (*Glycimeris*) *deleta*, *Venericardia Davidsoni*, *V. sulcata*, *Crassatella sulcata*, *Chama squamosa*, *Nummulites elegans*, *N. variolaria*.

In the London basin the position of the so-called "Upper Bagshot Sands" has been the subject of some discussion, there being no marked separation between them and the group known as "Middle Bagshot." They consist of sands with ferruginous concretions which have yielded *Turritella imbricataria*, *Ostrea flabellula*, and other shells found in the Barton Clay.

Above the Barton Clay and forming the highest member of the Eocene series comes a mass of unfossiliferous or sparingly fossiliferous sands, from 140 to 200 feet in thickness, so purely siliceous as to be valuable for glass-making. These deposits in the Isle of Wight are immediately covered by the base of the Oligocene series. They have been called "Upper Bagshot," but as they probably occupy a higher horizon than the true Upper Bagshot Sand of the London basin, the local term Headon Hill Sand or Barton Sand is more convenient for them.[4]

It is probably from the Bagshot sands that the great majority of the so-called "Grey Wethers" or "Druid stones" of the south of England have been derived, which have already (pp. 453, 464) been referred to.

[1] Ettingshausen, *Proc. Roy. Soc.* 1880, p. 228. See J. S. Gardner, *Geol. Mag.* 1877, p. 129; *Nature*, xxi. (1879), p. 181; the Monograph on Eocene Flora already cited, and "Geology of the Isle of Wight" in *Mem. Geol. Surv.* p. 104.

[2] J. S. Gardner, *Q. J. G. S.* xxxv. (1879), p. 209; xxxviii. (1882), p. 1; *Proc. Geol. Assoc.* v. p. 51; viii. p. 305; *Geol. Mag.* (1882), p. 470.

[3] *Quart. Journ. Geol. Soc.* xxxv. p. 227; xxxviii. p. 3. For an account of this deposit and its flora, consult W. Pengelly and O. Heer, *Phil. Trans.* 1862. See *postea*, p. 1251.

[4] C. Reid, "Geology of the Isle of Wight," *Mem. Geol. Surv.* p. 122.

Northern France and Belgium.[1] The anticline of the Weald which separates the basins of London and Hampshire is prolonged into the Continent, where it divides the Tertiary areas of Belgium from those of Northern France. There is so much general similarity among the older Tertiary deposits of the whole area traversed by this fold as to indicate a probable original relation as parts of one great tract of sedimentation. Local differences, such as the replacement of fresh-water beds in one region by marine beds in another, together with occasional gaps in the record, show us some of the geographical conditions and oscillations during the time of deposition. The following table gives the general grouping and correlation of the Eocene formations in this region:—

Upper.	Ludian or Priabonian.	Paris gypsum and marls.	
	Bartonian.	Limestone of St. Ouen. Sands of Beauchamp, &c. (Sables Moyens).	Wemmelian sands of Belgium.
Middle.	Lutetian.	Caillasses or Upper Calcaire Grossier (fresh-water).	Laekenian sands.
		Middle Calcaire Grossier (marine).	Bruxellian sands and sandstones.
		Lower Calcaire Grossier (fresh-water).	
Lower.	Londinian or Ypresian.	Sands of Cuise and Soissons.	Paniselian sands.
	Sparnacian.	Plastic clays and lignite.	
	Thanetian.	Limestones of Rilly and Sézanne.	Ypresian sands and clays.
		Sands of Bracheux.	Heersian marls and Landenian sands.

M. Gaudry has shown that this classification is borne out by the distribution of the mammalian remains in the successive subdivisions as indicated in the subjoined tabular statement:[2]—

Paris Gypsum (Ludian).	Appearance of the genera opossum, *Chæropotamus*, *Tapirulus*, *Anoplotherium* (Fig. 468), *Eurytherium*, *Cænotherium*, *Anchilophus*, *Acotherulum*, *Cebochœrus*, *Xiphodon*, *Amphimeryx*, *Pleuraetomys*, dormouse (?), *Trechomys*, *Galethylax* (?), *Hyænodon*, *Adapis*. Reign of pachyderms. The carnivora have still partly marsupial characters.
Sands of Beauchamp (Bartonian).	Appearance of the genera *Microchœrus*, *Chœromorus*, *Rhagatherium*, *Hyopotamus*, *Diplopus*, *Dichobune*, hedgehog (?), *Theridomys*, squirrel, *Sciuroides*, *Amphicyon*, *Cynodon*, bat.
Calcaire Grossier (Lutetian).	Appearance of the genera *Acerotherium* (?), *Palæotherium*, *Paloplotherium*, *Lophiodon*, *Pachynolophus*, *Pterodon*, *Proviverra*, *Cynopitherus*.
Sands of Cuise (Londinian).	Appearance of the genera *Hyracotherium* and *Pliolophus*.
Lignites of the Soissonnais (Sparnacian).	Appearance of the genera *Coryphodon* and *Palæonictis*.
Glauconitic sandstone of La Fére (Thanetian).	Appearance of *Arctocyon*.

[1] For a comparison of the Lower Eocene groups of Paris, Belgium, and England, see Hébert, *B. S. G. F.* (3), ii. p. 27. A. Rutot and G. Vincent, *Ann. Soc. Géol. Belgique* vi. (1879). Prestwich (*Brit. Assoc.* 1882, p. 538) regarded the Sables de Bracheux as representing only the lower part of the Woolwich beds.

[2] 'Les Enchaînements du Monde Animal dans les Temps Géologiques—Mammifères Tertiaires,' Paris, 1878, p. 4. Compare the American table, *postea*, p. 1245.

LOWER EOCENE (Paleocene).—In the Paris basin certain glauconitic sands form an excellent horizon, which corresponds to the Thanet Sand of England and Dumont's "Système Landenien" in Belgium.[1] They are sometimes indurated into a compact stone and are marked by the occurrence of *Cyprina scutellaria*. In the Department of the Oise they form the Sables de Bracheux—greenish glauconitic sands with a basement-band of green-coated flints resting generally directly on the Chalk. This sandy member of the series, traceable as a definite platform through the Anglo-French and Belgian area, contains among its characteristic fossils *Pholadomya cuneata*, *P. Koninckii*, *Cucullæa crassatina*, *Pecten* (*Propeamusium*) *breviauritus*, *Psammobia* (*Gari*) *Edwardsii*, *Ostrea bellovacina*, *Turritella bellovacina*, *Natica deshayesiana*, *Volutilithes depressus*. Above these sandy marine strata come the sands, marls, and limestones of Rilly near Reims, with fresh-water shells. Farther south these various deposits are replaced by the travertine of Sézanne, about fifteen feet thick, which has yielded a rich assemblage of terrestrial plants (*Chara*, *Asplenium*, *Alsophila*, *Juglandites*, *Sassafras*, *Vitis*, *Hedera*, &c.), together with caddis-worms, insects, and crustaceans.[2] The sandy strata at the base of the Eocene series of the north of France, together with the Rilly and Sézanne deposits, are classed as forming the Thanetian stage of the series. Above these deposits comes the "Argile plastique" of the Paris basin, with the associated

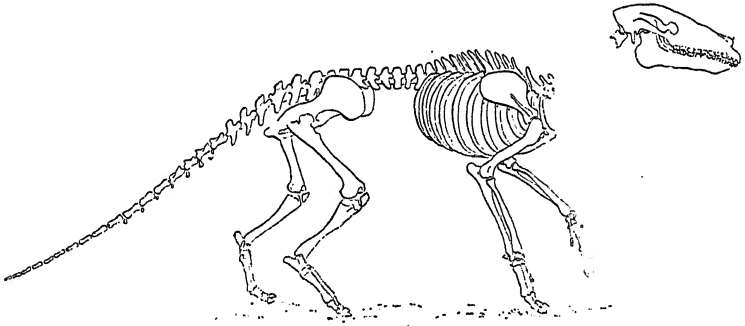

Fig. 468.—Anoplotherium commune, Cuv. (much reduced).

lignites of the Soissonnais. The molluscan fauna of these strata resembles that of the Woolwich and Reading beds, *Ostrea bellovacina*, *Melania* (*Melanatria*) *inquinata* and *Corbicula cuneiformis* being common shells. This division of the series has been named the Sparnacian stage from its development at Epernay (Sparnacum). The London Clay, though well represented in Belgium and French Flanders, does not extend into the Paris basin, where it appears to be represented by a group of sandy strata which, in the valley of the Aisne, are more than 150 feet thick, and overlie the lignites of the Soissonnais. These sands (Sables de Cuise or du Soissonnais) contain, among other abundant and well-preserved marine organisms, *Nummulites planulatus*, *Turritella edita*, *T. hybrida*, *Crassatella propinqua*, *Lucina squamula*. These strata, which may be the equivalent of the lower part of the English Bagshot Sand, form the highest member of the Lower Eocene stages of the Paris basin. From the typical development of this clay in the London basin this stage has been named Londinian; other writers have termed it Ypresian from Ypres in West Flanders, where the Belgian type of the clay is well seen.

The Lower Eocene formations in the Belgian area present some differences from those of the Paris basin. They have been grouped by Dumont into a series of "systèmes."

[1] Hébert, *Ann. Sciences Géol.* iv. (1873), Art. iv. p. 14. On the relations between the sands at the base of the Eocene series in the north of France and the Paris basin, see Gosselet, *Bull. Serv. Carte. Géol.* France, No. 8 (1890).

[2] Saporta, *Mém. Soc. Géol. France*, (2) viii.; 'Le Monde des Plantes,' p. 212 *et seq.*

Above the Montian, which is now placed at the top of the Cretaceous series, comes the "Système Heersien," so named from its development at Heers, in Limbourg. With a total depth of about 100 feet, it consists of (1) a lower division of sandy beds, with *Cyprina scutellaria*, *C. Morrisii*, *Modiola elegans*, and other marine shells, some of which occur in the Thanet Sand of England and the Sables de Bracheux; and (2) an upper division of marls (Marnes de Gelinden), containing, besides some of the marine shells found in the lower division, numerous remains of a terrestrial vegetation (*Osmunda eocenica*, *Chamæcyparis belgica*, *Poacites latissimus*, and species of *Quercus*, *Salix*, *Cinnamomum*, *Laurus*, *Viburnum*, *Hedera*, *Aralia*, &c.).[1]

The "Système Landenien," corresponding to the Woolwich and Reading beds of England and the Argile plastique and Lignites du Soissonnais of France, is divisible into two stages: 1st, Lower marine gravels, conglomerates, sandstones, marls, &c., with badly preserved fossils, among which are *Turritella bellovacina*, *Crassatella* (*crassatina*), *Protocardia Edwardsi*, *Cyprina scutellaria*, *Corbula regulbiensis*, *Pholadomya Koninckii*; 2nd, Upper fluvio-marine sands, sandstones, marls, and lignites containing *Melania* (*Melanatria*) *inquinata*, *Melanopsis buccinoides*, *Potamides funatus*, *Ostrea bellovacina*, *Corbicula cuneiformis*, with leaves and stems of terrestrial plants.

The "Système Ypresien" consists of a great series of clays and sands answering generally to the London Clay. It is divided into two stages: 1st, Lower stiff grey or brown clay (Argile de Flanders or d'Ypres), sometimes becoming sandy, and probably an eastward extension of the London Clay. The break between this deposit and the top of the Landenian beds below is regarded as filled up by the Oldhaven beds of the London basin. The only recorded fossils are foraminifera agreeing with those of the London Clay and some crustacea (*Xanthopsis*). 2nd, Upper sands with occasional lenticular intercalations of thin greyish-green clays, with abundant fossils, the most frequent of which are *Nummulites planulatus* (forming aggregated masses), *Turritella edita*, *T. hybrida*, *Vermetus bognoriensis*, *Pecten corneus*, *Pectunculus decussatus*, *Lucina squamula*, *Ditrupa plana*. Out of 72 species of mollusks, 45 are found also in the Sables de Cuise and 20 in the London Clay.[2]

The "Système Paniselien," so named from Mont Panisel near Mons, consists chiefly of sandy deposits not markedly fossiliferous, but containing among other forms *Rostellaria fissurella*, *Volutilithes elevatus*, *Turritella Dixoni*, *Meretrix* (*Cytherea*) *ambigua*, *Lucina squamula*. Out of 129 species of mollusca found in this deposit, 91 appear in the Sables de Cuise, and only 36 pass up into the Calcaire Grossier. Hence the Paniselian beds are placed at the top of the Lower Eocene stages of Belgium.

MIDDLE EOCENE.—This division is so fully developed in the Paris basin that the name of Lutetian (from Lutetia, the old appellation of Paris) has been given to it. It is there formed by the characteristic, prodigiously fossiliferous Calcaire Grossier which is subdivided as under:[3]—

(Caillasses or Upper Fresh-water) Calcaire Grossier.	Upper sub-group with *Cardium obliquum* and *Cerithium denticulatum*.	4. Limestone with *Cardium obliquum* and *Cerithium Blainvillei*.
		3. Limestone with *Cerithium denticulatum* and *Potamides cristatus*.
		2. Siliceous limestone with undetermined forms of *Potamides*.
		1. Coral limestone (*Stylocœnia*).
	Middle sub-group with *Lucina saxorum* and *Miliola*.	4. Siliceous limestone with parting of laminated marl.
		3. Limestone in small thin boards with *Corbula* (Rochette).
		2. Limestone with *Miliola* and *Lucina saxorum* (Roche).
		1. Siliceous limestone with indeterminate fossils (Banes francs).

[1] De Saporta and Marion, *Mém. Cour. Acad. Roy. Belg.* xli. (1878).

[2] Mourlon, 'Geol. Belg.' p. 211.

[3] Dollfus, *B. S. G. F.* 3e sér. vi. (1878), p. 269; Michelet, *op. cit.* 2e sér. xii. p. 1336.

Lower group with *Potamides lapidum* and *Miliola*.

1. Limestone (dolomitic) with *Miliola* (Cliquart).
3. Green marl . . . . / Siliceous limestone in two beds / Green marl . . . . — Banc vert.
2. Miliola limestone (dolomitic) (Saint Nom).
1. Siliceous limestone with *Potamides*.

5. Limestone with *Lucina concentrica*, *Arca barbatula*, *Cardium* (*Litho-[illegible]*) [illegible], *Miliola*, &c.
4. Limestone with *Orbitolites*, *Sycum bulbiforme*, *Volvaria bulloides*, *Car-*[illegible], *Arca quadrilatera*, several species of large *Flustra* or *Membranipora*.
3. Limestone with *Fabularia* and terrestrial vegetation (*Orbitolites com-planata*, *Chama calcarata*, *Venericardia imbricata*, &c.).
2. Mass of *Miliola* limestone (*Turritella imbricataria*, *Chama calcarata*, *Lucina* [illegible], &c.).
1. Limestone with *Miliola* and *Terebratula* (*T. bisinuata*).
5. Glauconitic calcaire grossier with *Cerithium* (*Campanile*) *giganteum* (Banc à Vérins).
4. Glauconitic calcareous sand with *Lenita patellaris*.
3. Sandy glauconitic calcaire grossier, with *Cardium porulosum*.
2. Sandy glauconitic calcaire grossier, with *Nummulites lævigatus*, *N. scaber*, *Ostrea* [illegible], *O. flabellula*, *Ditrupa plana*.
1. Glauconitic sand, sometimes calcareous and indurated, with pebbles of green quartz, shark's teeth, and rolled fragments of coral.

The Lutetian stage of the Paris basin is regarded as the probable equivalent of the Lower Bagshot sands and the clays of Bracklesham and Bournemouth in the English Tertiary series. In Belgium the Middle Eocene presents a different aspect from that of Paris, approximating rather to the English type. It consists of (1) a lower set of sandy beds about 150 feet grouped under the name of "Bruxellien," rich in fossils, which, however, are usually badly preserved. Among the forms are remains of terrestrial vegetation (*Nipadites Burtini*), also *Paracyathus crassus*, *Maretia grignonensis*, *Pyripora* [illegible], *Ostrea* [illegible], *Cardita* [illegible], *Modiola decussata*, *Chama calcarata*, *Cardium poru-losum*, [illegible], *Natica labellata*, *Voluta lineola*, *Ancilla* [illegible], *Fusus* [illegible], numerous remains of fishes, especially of the genera *Myliobatis*, [illegible], *Lamna*, *Galeocerdo*, and various reptiles, including species of [illegible] and [illegible], with *Emys Camperi*, *Gavialis Dixoni*, and *Palæophis typhæus*; (2) a group of sands and fossiliferous calcareous sandstones ("Laekenian"), made up of [illegible] *N. lævigatus*, *N. scaber*, *N. Héberti*, *N. variolarius*), and [illegible].

During Middle Eocene time some fissures in the Jurassic limestone were filled in from the surface with deposits in which the carcases were covered up of many of the animals of the time that frequented the region. Among these deposits the most noted is the breccia of Egerkingen in the Canton of Solothurn, from which a remarkable assemblage of terrestrial animal remains has been obtained, including lemuroids (*Cænopithecus*, *Adapis*, [illegible]), cheiroptera (*Vespertiliavus*), creodonts (*Proviverra*, *Pterodon*), true carnivores [illegible], rodents (*Plesiarctomys*, *Sciurus*, *Sciuroides*), ungulates ([illegible], *Hyopotamus*, *Cebochærus*, *Sus*, *Lophiodon*, *Pachyno-lophus*, *Palæotherium*, *Paloplotherium*, *Anchilophus*, *Phenacodus*, *Meniscodon*, &c.).[1]

Upper Eocene.—In the Paris basin this subdivision consists of the following stages:[2]

First band of gypsum (Haute masse or Gyps lacustre).[3] This highest and [illegible] gypsum bed of the Paris basin (65 feet thick at Montmartre),

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[1] L. Rütimeyer, [illegible] *Basel*, ix. (1890), Heft. 2.

[2] See Dollfus, *op. cit.*

[3] For a detailed account of the interesting mineralogy of the gypseous deposits of the Paris basin, see A. Lacroix, *Nouv. Arch. Muséum*, ix. Paris, 1897. The Paris gypsum and marls form the stage termed "Ludian," from Ludes in the Montagne de Reims, or "Pria-

Paris Gypsum or Ludian.

displays a remarkable prismatic structure (p. 661), and contains skeletons and bones of mammals (*Palæotherium, Anoplotherium, Xiphodon, Chæropotamus*), [illegible] of terrestrial wood, and a few terrestrial shells (*Helix, Cyclostoma*, &c.). It is conformable with the marls and marine gypsum underneath.

Marls with nodules of silica (menilite) and gypsum.

Second band of gypsum, containing marine fossils (*Potamides tricarinatus, P. (Batillaria) pleurotomoides, Mesalia inserta*).

Yellow marls with *Lucina inornata*.

Third band of gypsum, saccharoid and crystallised, with brown marls.

Yellow, brown, and greenish marls, with *Pholadomya ludensis, Corbula Desmaresti*, &c.

Fourth band of gypsum.

Sables Moyens or Bartonian.[1]

Green sands of Monceaux (*Potamides Cordieri, P. tricarinatus, Ampullina parisiensis*).

Limestones of Saint Ouen—a marly fresh-water rock 20 to 26 feet thick, composed of two zones, the lower full of *Bithinia*, and the upper abounding in *Limnæa*.

Sands of Mortefontaine (*Avicula Defrancei*).

Limestone of Ducy (*Limnæa, Hydrobia*).

Sands and sandstones of Beauchamp (*Cerithium mutabile, C. tuberculosum, Potamides Bouei, Bayania hordacea, B. lactea, Cochlearia depressa, Planorbis (Anisus) nitidulus, Corbula gallica*, &c.).

Sands, &c., with *Nummulites variolarius, Ostrea multistriata, O. [illegible], Corbicula deperdita*, corals, *Odontaspis elegans, Lamna elegans*, &c.

Northwards in the Belgian area, near Brussels, the highest Eocene strata consist of sands and calcareous sandstones ("Wemmelien"), separated from the similar Laekenian beds below by a gravel full of *Nummulites variolarius*. Other common fossils are *Turbinolia sulcata, Corbula pisum, Venericardia sulcata, Turritella brevis, Clavilithes (Fusus) longævus*.

Receding from the Paris basin, the Eocene deposits assume entirely different characters as they are traced into the west, centre, and south of France. According to Vasseur's detailed researches, a long irregular arm of the sea penetrated Brittany in Eocene times, from where the Loire now enters the Atlantic, while the south-western part of Vendée was likewise submerged. In these waters a series of limestones and sands was deposited, which from their fossil contents appear to be the equivalents of the Calcaire Grossier. They pass up into lacustrine and brackish-water beds like the corresponding groups at Paris.[2] In the south of France, the Eocene rocks consist partly of marine, partly of fresh-water formations. In Provence, where the Upper Cretaceous deposits are of fresh-water origin, the sedimentation was continued without interruption into Tertiary time, and the whole of the succession of strata referable to the Eocene series was deposited in lakes or rivers. The fossils include species of *Chara, Limnæa, Planorbis, Bulimus, Achatina, Helix, Clausilia*, &c., together with remains of plants, fishes, insects, and mammals (*Palæotherium, Anchitherium, Anoplotherium*).[3]

Westward from this region of terrestrial waters the most distinctive member of the Eocene series is the massive limestone which presents the nummulitic facies to be immediately referred to, and in some places attains a great development, as near Biarritz, where it is more than 3000 feet thick.

Southern Europe.—The contrast between the facies of the Cretaceous system in north-western and in southern Europe is repeated with even greater distinctness in the Eocene series of deposits. From the **Maritime Alps** into the Apennines and Greece,

bonian," from Priabona in the Euganean Hills, where the southern type of the stage is well shown.

[1] This stage has received the name of "Bartonian," from the English Barton Clay.

[2] G. Vasseur, *Ann. Sci. Géol.* xiii. (1881). Hébert, *B. S. G. F.* (3) x. (1882), p. 364.

[3] Matheron, *B. S. G. F.* 3e sér. iv. ; G. Vasseur, "Note préliminaire sur la constitution du Bassin Tertiaire d'Aix-en-Provence" 1897.

from the Carpathian Mountains and the Balkan into Asia Minor, and thence through Palestine into northern Africa on the one side, and through Persia and the heart of Asia to the shores of China and Japan on the other, a series of massive limestones has been traced, which, from the abundance of their characteristic foraminifera, have been called the Nummulitic Limestone. Unlike the thin, soft, modern-looking, undisturbed beds of the Anglo-Parisian area, these limestones attain a depth of sometimes several thousand feet of hard, compact, sometimes crystalline rock, passing even into marble; and they have been folded and fractured on such a colossal scale that their strata have been heaved up into lofty mountain crests sometimes 10,000, and in the Himalaya range more than 16,000 feet above the sea. With the limestones is associated the sandy series known as Nummulitic Sandstone. The massive unfossiliferous Vienna sandstone and Flysch, already referred to as probably in part Cretaceous, are also partly referable to Eocene and even later times.[1] One of the most remarkable features of these Alpine Eocene deposits is the occurrence in them of coarse conglomerates and gigantic erratics of various crystalline rocks. As far east as the neighbourhood of Vienna, and westward at Bolgen near Sonthofen in Bavaria, near Habkeren and in other places, blocks of granite, granitite, and gneiss occur singly or in groups in the Eocene strata. These travelled masses appear to have most petrographical resemblance, not to any Alpine rocks now visible, but to rocks in Southern Bohemia. Their presence has been thought to indicate the existence of glaciers in the middle of Europe during some part of the Eocene age.[2] Another interesting Eocene deposit of the Alpine region is the coal-bearing group of Häring, in the Northern Tyrol, where a seam of coal occurs which, with its partings, attains a thickness of 32 feet.

The Nummulitic series has been divided into stages in different regions of its distribution, and attempts have been made by means of the included fossils to parallel these stages in a general way with the subdivisions in the Anglo-Parisian basin. But the conditions of deposition were so different that such correlations must be regarded as only rude approximations to the truth. In the Northern Alps (Bavaria, &c.) Gümbel arranged the Eocene series as under:[3]

Flysch (or Vienna sandstone)—Upper Eocene, including younger Nummulitic beds and Häring beds.
Lower Nummulitic group—Kressenberg beds—greenish sandy strata abounding in Nummulites, &c., and pointing to a correspondence with the Calcaire Grossier.

[1] The origin of the Flysch has given rise to some discussion. Th. Fuchs, for instance, regarded it as having probably been derived from eruptive discharges such as those of mud volcanoes (Sitzb. Akad. Wien, lxxv. (1877), p. 340; *Verh. Geol. Reichsanst.* 1878, p. 135). This view was opposed by K. M. Paul, who looked on the Flysch as a normal sedimentary formation (*Jahrb. Geol. Reichsanst.* 1877, p. 431; *Verh. Geol. Reichsanst.* 1878, p. 179). By some geologists the rocks have been regarded as a deep-sea deposit, by others as formed in shallow water (Renevier, *Arch. Sci. Phys. Nat. Geneva*, [illegible] 1884, p. [illegible]); see also Mantovani, *Neues Jahrb.* 1877; Schardt and Favre, 'Description géologique des Préalpes du Canton de Vaud,' &c. 1887. Kauffmann, 'Description de [illegible] de la Carte Géol. Suisse,' 1886. F. Sacco, *Bull. Soc. Belge de Géol.* [illegible] p. [illegible]. C. Mayer Eymar, 'Versuch einer Classification der tertiär Gebilde Europa's,' [illegible] *Naturf. Ges.* 1857. The Flysch is usually comparatively poor in fossils, though it has yielded a good many fucoids. In some of its later portions [illegible] fish remains in certain layers. C. Mösch, *Beiträge Geol. Karte Schweiz*, [illegible]. A. Rothpletz, *Z. D. G. G.* xlviii. (1896), p. 854.

[2] That a glacial period occurred at the close of the Cretaceous, at the end of the Eocene, and again in the Miocene period (erratics of Superga, near Turin) has been regarded by some geologists as probable (A. Vezian, *Rev. Sci.* xi. (1877), p. 171; Schardt, 'Etudes Géologiques sur le pays d'Enhaut Vaudois,' *Bull. Soc. Vaud.* 1884).

[3] 'Geognostische Beschreib. Bayerisch. Alpen,' 1861, p. 593 *et seq.*

Burberg beds—greensand with small Nummulites and *Exogyra Brongniarti*, answering possibly to the upper part of the lower Eocene beds of the Anglo-Parisian area.

In the southern and south-eastern Alps the Eocene rocks attain a much larger development. The following subdivisions in descending order have been recognised :[1]—

Upper Eocene.	Macigno or Tassello, having the usual character of the Vienna sandstone. No fossils but fucoids.
	Fossiliferous calcareous marls and shales, and thick conglomerates.
Nummulite-Limestone.	Chief Nummulite limestone, containing the most abundant and varied development of nummulites, and attaining the thickest mass and widest geographical range.
	Borelis (Alveolina) limestone, containing numerous large foraminifera of the genus *Borelis*.
	Lower Nummulite limestone, with small nummulites, and in many places banks of corals.
Liburnian Stage.	Upper Foraminiferal limestone, containing also intercalations of fresh-water beds (*Chara*).
	Cosina beds, with a peculiar fresh-water fauna (*Stomatopsis*, *Melania*, *Chara*, &c.).
	Lower Foraminiferal limestone, with numerous marine mollusca (*Anomia*, *Cerithium*, &c.), and occasional beds of fresh-water limestone (*Chara*, *Melania*, &c.).

In the central part of the northern Apennines Professor Sacco regards as Eocene a mass of strata 5500 feet thick, which he subdivides as follows:[2]—

Bartonian. 100 metres.	Grey marls with sandy calcareous layers ; numerous fossils (*Zoophycus*, *Lithothamnium*, *Nummulites Tchihatcheffi*, *N. striata*, *Orbitoides radians*, *Operculina*, corals, bryozoa, crinoids, &c.)
Parisian. 1500 metres.	A thick series of marly and shaly limestones (Flysch), alternating with sandstones (*Helminthoidea labyrinthica*, *Chondrites*, and other fucoids). Roofing slates.
	Shales and sandstones (Macigno).
	Sandy greyish and brownish marls with calcareous sandy beds (*Lithothamnium*, *Nummulites biarritzensis*, *N. Lamarcki*, *N. lucasanus*, *Assilina exponens*, *A. granulosa*, *Orbitoides*, *Operculina*, *Alveolina*, corals, echini, crinoids, fish-teeth, &c.).
Suessonian. 100 metres.	Shales and grey and brown marls, sandstones and limestones.

To the Upper Eocene series of this region has been assigned a great series of serpentines, gabbros, diabases, soda-potash granites, and other eruptive rocks, with tuffs and conglomerates, marking copious marine volcanic activity.[3]

India, &c.—As above stated, the massive Nummulitic limestone extends through the heart of the Old World, and enters largely into the structure of the more important mountain chains. In India a tolerably copious development of Eocene rocks has been

[1] Von Hauer, 'Geologie,' p. 569. For an exhaustive account of the stratigraphy and palæontology of the Liburnian stage, see G. Stache's great monograph, 'Die Liburnische Stufe,' *Abhandl. k. k. Geol. Reichsanst.* xiii. 1889. On the classification of the older Tertiary formations of Austria, consult Tietze, *Z. D. G. G.* xxxvi. (1884), p. 68 ; xxxviii. (1886), p. 26 ; T. Fuchs, *op. cit.* xxxvii. (1885), p. 131.

[2] Professor Sacco has contributed many papers on this subject. See, for example, *B. S. G. F.* (3) xvii. (1889), p. 212, and a series in *Boll. Soc. Geol. Ital.* (from 1892 onwards) xi. xii. xiv. xviii. Professor Trabucco, C. de Stefani, B. Lotti, and O. Marinelli have also written on these regions.

[3] C. de Stefani, *Boll. Soc. Geol. Ital.* viii. fasc. 2 (1889) ; a copious list of previous writers on the subject will be found in this paper, also B. Lotti, 'Descrizione Geologica dell' Isola d'Elba,' Rome, (1886), p. 68.

observed, but it is not quite certain where their upper limit should be drawn so as to place them on a parallel with the corresponding groups in Europe. The following subdivisions in descending order are observed in Sind:[1]—

Nari group. Sandstones without marine fossils, but containing fragmentary plants, and probably of fresh-water origin, 4000 to 6000 feet, with nummulitic limestones and shales in the lower part, representing, perhaps, Upper Eocene and Oligocene or Lower Miocene beds of Europe.

Kirthar group. A marine limestone formation in general, but passing locally into sandstones and shales, 6000 to 9000 feet. The massive nummulitic limestone of this division forms all the higher ranges in Sind.

Ranikot beds—sandstones, shales, clays with gypsum and lignite, 1500 to 2000 feet; abundant marine fauna, including *Nummulites spira*, *N. irregularis*, *N. Leymeriei*, together with Nautili, Terebratulæ and other fossils of Cretaceous affinities.

Along the southern front of the Himalayan chain a vast succession of Tertiary deposits exists, of which the older part includes thick masses of nummulitic limestone, no doubt a continuation of the Eocene formations of Southern Europe, while the upper part (Siwalik series) is made up of subaerial or fluviatile accumulations of later (partly Miocene) date. In the Simla district the lower Tertiary or Sirmur series contains the following subdivisions:—

Kasauli group of sandstones, containing no fossils but remains of plants, and probably of fluviatile or subaerial origin.

Dagshai group of hard grey sandstones and bright red nodular clays; generally unfossiliferous, yielding only fucoid markings and annelid tracks.

Subáthu group of greenish and red gypseous shales and impure limestones, with shales and some poor coal. The group contains numerous marine fossils and is of the age of the upper part of the thick nummulitic series of the north-west area.

Farther west the nummulitic series attains a great thickness. In the Salt Range its principal member is a fine compact grey or white, frequently cherty limestone 400 or 500 feet thick, which is unconformably surmounted by the Upper Tertiary series. Beneath it lie some shales or clays 50 to 100 feet thick including one or more coal-seams.[2]

North America.—Tertiary formations of marine origin extend in a strip of low land along the Atlantic border of the United States and Mexico, from the north of New Jersey southward through Delaware, Maryland, Virginia, the Carolinas, and Georgia into Florida and round the margin of the Gulf of Mexico, whence they run up the valley of the Mississippi to beyond the mouth of the Ohio. On the western seaboard they also occur in the coast ranges of California and Oregon, where they sometimes have a thickness of 3000 or 4000 feet, and reach a height of 3000 feet above the sea. Over the Rocky Mountain region Tertiary strata cover an extensive area, but are chiefly of fresh-water origin.

In the States bordering on the Atlantic the series of deposits classed as Eocene is well developed in that portion of the Tertiary belt traversed by the Potomac River, where it presents the following section of about 300 feet of strata, which are regarded by Professor W. B. Clark as representative of the lower and middle Eocene divisions of the Gulf States, with perhaps some portion of the upper groups also.[3]

		Feet.
Woodstock Group.	Greensand with *Ostrea sellæformis*, *Pectunculus idoneus*, *Protocardia virginiana*	40
	Greensand with few fossils, chiefly *Venericardia planicosta*	50

[1] 'Geology of India,' 2nd edit. chap. xiv.

[2] 'Geology of India,' p. 352.

[3] W. B. Clark, *B. U.S. G. S.* No. 141 (1896), pp. 41, 58.

Aquia Creek Group.		Feet.
	Greenish-grey argillaceous sand	25
	Greenish-grey argillaceous sand with bands of gypsum crystals	4
	Light-grey greensand with *Venericardia planicosta*	3
	Greenish-grey argillaceous sand	8
	Indurated argillaceous sand (with some specimens of *Venericardia planicosta*)	2
	Greenish-grey sand, somewhat argillaceous (*Cytherea*)	25
	Thick-bedded indurated greensand, the layers of which are almost entirely made up of *Turritella Mortoni*	14
	Characteristic light greenish-grey greensands and greensand-marls, with *Turritella Mortoni, T. humerosa, Cucullæa gigantea, Crassatella alæformis, Ostrea compressirostra*, &c.	30
	Greensand with fragments of shells of lower beds	7
	Greensand full of the common fossils of the underlying strata, and also several species of corals (*Eupsammia elaborata, Turbinolia acuticostata, Paracyathus* (?) *Clarkeanus*)	1
	Persistent band of indurated calcareous greensand crowded with fossils, which besides those characteristic of the beds below include conspicuously *Pholadomya marylandica, Panopæa elongata, Tellina virginiana, Calyptræa aperta* (*trochiformis*), *Fusus trabeatus*, &c.	2
	Typical greensand with *Crassatella alæformis, Meretrix* (*Cytherea*) *ovata, Dosiniopsis lenticularis*, &c.	8
	Indurated highly glauconitic greensand or limestone filled with casts of the same shells as in the bed above, together with *Ostrea compressirostra*, and a few of *Turritella Mortoni*	3
	Dark greensand crowded with the same shells, and especially with *Crassatella alæformis, Dosiniopsis lenticularis*, and *Meretrix* (*Cytherea*) *ovata*	12
	Greensands, at times argillaceous, but almost wholly unfossiliferous; at the base lies a pebble-bed which sometimes rests on the Cretaceous formations	60

Besides the fossils enumerated in this table these deposits have furnished a number of species of foraminifera (*Spiroplecta, Nodosaria, Vaginulina, Cristellaria, Polymorphina, Globigerina, Pulvinulina*, &c.), also species of *Anomia, Pecten, Nuculana, Venericardia, Astarte, Lucina, Corbula, Natica, Mitra, Volutilithes*, together with some fishes (*Galeocerdo, Odontaspis, Oxyrhina, Lamna, Carcharodon, Myliobatis*), chelonians (*Trionyx*) and crocodiles (*Thecachampsa*).[1]

In the State of Mississippi the Eocene strata are well developed and have been subdivided into five groups, as in the following table:[2]—

5. Vicksburg beds (Orbitoitic) which run in a narrow band through Alabama, Mississippi, and Louisiana, covering the greater part of Florida, and extending into Georgia and Texas. These strata in Mississippi are composed of a lower ferruginous rock (Red Bluff) 12 feet thick, and a set of crystalline limestones and blue marls (80 feet) resting on lignitic clays and lignites (20 feet). Among the fossils are *Ostrea gigantea, Pecten Poulsoni, Cardium diversum, Venericardia planicosta, Panopæa oblongata, Cypræa lintea, Mitra mississippiensis, Cassidaria lintea, Conus sauridens, Madrepora mississippiensis, Flabellum Wailesii, Orbitoides Mantelli*. The last-named fossil is specially characteristic, and is found also in the West Indies, Malta, and the Turco-Persian frontier.
4. Jackson beds ("White Limestone" of Alabama), white and blue marls underlain by lignitic clay and lignite (80 feet), with *Zeuglodon macrospondylus, Venericardia planicosta, Cardium Nicolleti, Nuculana multilineata, Corbula bicarinata, Rostellaria velata, Voluta dumosa, Mitra dumosa, Conus tortilis, Cypræa fenestralis*, &c.
3. Claiborne beds, white and blue marls, and sandy beds with numerous shells which indicate a horizon equivalent to that of part of the Calcaire Grossier of the Paris basin.

[1] W. B. Clark, *op. cit.* p. 58 *seq.*

[2] A. Heilprin, 'Contributions to the Tertiary Geology and Palæontology of the United States,' 1884; *Proc. Acad. Philadelph.* 1887.

2. Buhrstone (Siliceous Claiborne), sandstones and siliceous impure limestones with Claiborne fossils (400 feet and upwards).
1. Lignitic sands and clays, with marine fossils, and with interstratified lignites and plant-remains (*Quercus*, *Populus*, *Ficus*, *Laurus*, *Persea*, *Cornus*, *Olea*, *Rhamnus*, *Magnolia*, &c.).

Over the Rocky Mountain region and the vast plateaux lying to the east of that range especially in Utah, Wyoming, Colorado, and New Mexico, the older Tertiary formations consist mainly of fresh-water strata of great thickness, the extraordinary richness of which in vertebrate and particularly mammalian remains, already referred to (p. 1227), has given them a high importance in geological and palæontological history. The following subdivisions in descending order have been adopted :[1]—

Upper.	Telmatotherium and Diplacodon Beds.	Uinta group (800 feet), developed to the south of the Uinta Mountains in Utah, includes three fossiliferous horizons : C, the Upper or true Uinta, containing *Hyopsodus*, *Paramys*, *Prodaphænus*, *Oxyænodon*, *Mesonyx*, *Epihippus*, *Isectolophus*, *Triplopus*, *Amynodon*, *Telmatotherium*, *Palæosyops*, *Diplacodon*, *Bunomeryx*, *Leptoreodon*, *Eomeryx*, *Protelotherium*; B, the Lower Uinta or Telmatotherium beds, containing *Prodaphænus*, *Oxyænodon*, *Telmatotherium* (several species), *Palæosyops*, *Leptoreodon*, *Protelotherium*; and A, which is probably the equivalent of the upper part of the Bridger group below.
Middle.	Uintatherium Beds.	Bridger group (2000 feet), so named from the Fort Bridger basin, remarkable for its abundant and varied fauna, which includes numerous lemuroids (*Hyopsodus*, *Microsyops*, *Notharctus*, *Omomys*, *Anaptomorphus*), rodents (*Paramys*, nearly a dozen species), creodonts (*Miacis*, *Viverravus*, *Sinopa*, *Patriofelis*), tillodonts (*Tillotherium*), edentates (*Stylinodon*), amblypods (*Uintatherium*=*Deinoceras* and *Tinoceras*, between 30 and 40 species), primitive forms of horse (*Orohippus*, &c.), hyracodonts (*Hyrachyus*, seven or more species), titanotherids (*Palæosyops*, *Telmatotherium*), ungulates (*Homacodon*, &c.), insectivores, bats and tapirs.
Lower.	Bathyopsis Beds.	Wind River group (800 feet) from the Wind River in Wyoming. Among its characteristic vertebrates are species of *Hyopsodus*, *Pelycodus*, *Microsyops*, *Paramys*, *Viverravus*, *Uintacyon*, *Sinopa*, *Esthonyx*, *Phenacodus*, *Coryphodon*, *Bathyopsis*, *Hyracotherium*, *Protorohippus*, *Lambdotherium*, *Heptodon*, *Telmatotherium*.
	Coryphodon Beds.	Wasatch group (2000 feet) named from the Wasatch Mountains in Utah, (*Hyopsodus*, six species; *Pelycodus*, five species ; *Paramys*, *Viverravus*, *Uintacyon*, *Palæosinopa*, *Sinopa*, seven species ; *Oxyæna*, *Palæonictis*, *Pachyæna*, *Esthonyx*, *Calamodon*, *Phenacodus*, *Meniscotherium*, *Coryphodon*, nine or more species ; *Hyracotherium*, *Systemodon*, *Trigonolestes*.
Basal.	Pantolambda Beds.	Torrejon group (300 feet), from a locality in north-western New Mexico where the strata were studied. The fauna is marked by the absence of many of the characteristic forms of the later formations, and by the presence of *Ptilodus*, *Neoplagiaulax*, *Chirox*, *Indrodon*, *Mixodectes*, *Tricentes*, *Chriacus*, *Deltatherium*, *Goniacodon*, *Dissacus*, *Clænodon*, *Periptychus* (*Catathlæus*) *Euprotogonia*, *Mioclænus*, *Pantolambda*, *Psittacotherium*, *Conoryctes*.
	Polymastodon Beds.	Puerco group (500 feet), from the Puerco River, New Mexico, containing a fauna which is believed to be older than any mammalian fauna in Europe. The strata of the group immediately overlie the Upper Cretaceous formations and contain *Polymastodon*, *Neoplagiaulax*, *Protochriacus*, *Triisodon*, *Oxyacodon*, *Periptychus* (*Catathlæus*), *Conacodon*, *Protogonodon*, *Hemiganus*, *Onychodectes*, &c.

The various deposits enumerated in the foregoing table, whether they are regarded as having been laid down in lakes or spread out subaerially by running water, occupy detached though extensive areas, and their stratigraphical sequence cannot in many cases be determined by actual superposition. They have consequently been to some

[1] H. F. Osborn, *Bull. Amer. Mus. Nat. Hist.* vii. (1895), p. 75 ; viii. (1896), p. 157 ; W. D. Matthew, *op. cit.* xii. (1899), p. 19.

extent correlated on the basis of palæontological evidence. Such correlation may not be always accurate, for the evidence is sometimes incomplete, and may be misleading. The difficulty of making a satisfactory parallelism is well brought out by the history of the Tertiary formations of the Denver basin, Colorado. The strata originally grouped there under the name of "Laramie" have been found to comprise three formations: (1) a lower member, 700 to 800 feet thick, conformable with the Cretaceous Fox Hills group, containing productive coal-seams and a flora and fauna characteristic of the Laramie group as now understood; (2) a middle member, called the Arapahoe group, 600 to 800 feet thick, resting on the first unconformably, with a conglomerate at its base, containing pebbles of the underlying formation and other older rocks; (3) an upper member, the Denver group, 1400 feet thick, unconformable to the middle division, and largely composed of the débris of andesitic lavas. The strong unconformability between the true Laramie beds (No. 1) and the overlying formations indicates a prolonged interval of time. The Arapahoe and Denver groups have yielded a considerable number of plants and vertebrates, but some difference of opinion exists as to the conclusions to be drawn from the collections which have been made. Marsh regarded his "Ceratops beds" as Cretaceous, from which many of the animal remains came. On the other hand, Cope and Osborn have suggested that the assemblage of fossils rather resembles that of the Puerco group.[1] In Southern Colorado the Eocene strata have been described as 7000 feet thick, resting unconformably on the Laramie series. The lowest member (Poison Cañon), 3500 feet thick, and the next division (Cuchara), 300 feet thick, are classed as Lower Eocene; the upper (Huerfano), 3300 feet thick, is believed to be equivalent to the Bridger group.[2]

On the Pacific slope Eocene formations attain a thickness of several thousand feet in California and Oregon, where they form the Tejon series. In their lower parts they consist of conglomerates which pass up into sandstones and these into shales. In north-western Oregon they include basalts and tuffs below, covered by thick shales containing much material of igneous origin, while in the upper part massive sandstones predominate. The tuffs were of submarine origin, for they contain *Modiola*, *Turritella*, *Ostrea*, and other shells. The shales have yielded *Liocardium linteum*, *Venericardia planicosta*, *Modiola ornata*, with occasional intercalations of plant-bearing sediments and coal-seams.[3]

South America.—The stratified deposits of Patagonia have given rise to much confusion of description. From the latest descriptions of the geologists of the Princeton University Expedition, it would appear that the uppermost (Guaranitic) Cretaceous strata (p. 1218) were deeply eroded before the deposition unconformably upon them of the oldest Tertiary formations, and that the supposed coexistence of Cretaceous and later Tertiary mammalian types has arisen from inaccurate observations of the stratigraphical relations of the rocks. After prolonged exposure and denudation of the Cretaceous series the region subsided under the sea, which then laid down the oldest Tertiary deposits, known as the Magellanian series. From the marine fossils contained in them, these strata are regarded as of late Eocene or early Oligocene age. They include leaf-beds, and in their upper parts several seams of pure lignite varying from a few inches to ten or twelve feet in thickness.[4]

Australasia.—Vast areas in this region are covered with strata that sometimes attain a depth of several hundred feet, containing both terrestrial and marine deposits, which

[1] Whitman Cross, *Amer. Journ. Sci.* xxxvii. (1889), p. 261; xliv. (1892), p. 19; *Proc. Colorado Sci. Soc.* Oct. 1892; *Monograph U.S. G. S.* No. xxvii. (1896), p. 155. In this last-named essay the difficulties of correlation are stated in much detail.

[2] R. C. Hills, *Proc. Colorado Sci. Soc.* iii. (1888), p. 148; (1889), p. 217 (1891).

[3] J. S. Diller, 'A Geological Reconnaissance of North-Western Oregon,' 17*th Ann. Rep. U.S. G. S.* 1896.

[4] J. B. Hatcher, *Amer. Journ. Sci.* ix. (1900), p. 97.

have been grouped with more or less confidence according to the accepted classification of the Tertiary formations. It is at least certain that a succession can be traced among them, with an increasing proportion of recent species in the younger parts of the series. Throughout the whole of Eastern Australia, including most of New South Wales and Queensland, no marine Tertiary fossils have been discovered. In the south-west of New South Wales and in Victoria, previous to the eruption of basalt-sheets and tuffs, an extensive series of conglomerates, siliceous sandstones, clays, ironstones, and lignites was deposited in valleys and probably lake-basins. On the Dividing Range these strata rise to 4000 feet above the sea. At Bacchus Marsh in Victoria and elsewhere they have yielded leaves of *Laurus*, *Cinnamomum*, *Ginkgo*, *Lastræa*, *Tæniopteris*, &c. Above these plant-bearing beds, which have been regarded as Lower Miocene, but may be Eocene or even Cretaceous, marine deposits supposed to be Middle and Upper Miocene occur on the flanks of the Dividing Range of New South Wales up to heights of 800 feet. In South Australia and Victoria extensive marine accumulations of clay, sand, and limestone, often underlying widespread basalt-plateaux, have yielded numerous foraminifera, especially at Mount Gambier and Murray Flats in South Australia; upwards of 50 species of corals, which are only slightly related to the living species of the surrounding seas, but include three European Tertiary species;[1] many echinoderms and polyzoa, and a large molluscan fauna, in which the genera *Waldheimia*, *Cucullæa*, *Pectunculus*, *Trigonia*, *Cypræa*, *Fusus*, *Haliotis*, *Murex*, *Mitra*, *Trivia*, *Turritella*, *Voluta*, &c., occur. The vertebrate organisms consist of fishes (including the world-wide genera *Carcharodon*, *Lamna*, *Odontaspis*, *Oxyrhina*), a few marsupials (*Bettongia*, *Nototherium*, *Phascolomys*, *Sarcophilus*), with some marine mammalia (*Squalodon*, *Arctocephalus*). At the head of the Great Australian Bight, an Eocene chalk-rock with flints and polyzoan limestones, forms cliffs about 250 feet high, but descends more than twice that depth beneath the surface. In South Australia the older Tertiary deposits have been divided by Professor Tate into four groups, which in ascending order are: (*a*) Inferior marine beds, chalk-rocks, clays, and limestones; (*b*) Lower Murravian sandstones with *Zeuglodon*, *Lovenia*, *Magasella*, *Megalaster*; (*c*) Middle Murravian limestones and sandstones, with an abundant and varied marine fauna (*Carcharodon*, *Lamna*, *Odontaspis*, *Nassa*, *Ancilla*, *Cassis*, *Voluta*, *Marginella*, *Mangilia*, *Cerithium*, *Conus*, *Cancellaria*, *Natica*, *Pecten*, *Lima*, *Spondylus*, *Nucula*, *Limopsis*, *Chama*, *Chione*, *Rhynchonella*, *Terebratulina*, *Waldheimia*, *Terebratula*, *Eupatagus*, *Deltocyathus*, &c.; (*d*) Upper Murravian oyster-beds and sandstones (*Trigonia*, *Pectunculus*, *Tellina*, *Mactra*, *Clypeaster*, &c.).

In Tasmania an important series of older Tertiary deposits has also been found. At the top, leaf-beds, lignites, and beds with marine fossils occur, associated with extensive sheets of felspar-basalts and tuffs. The tuffs have yielded *Hypsiprimnus* and *Phascolomys*. Next comes a great series of sandstones, clays, and lignites, varying from 400 to 1000 feet in thickness, and sometimes, as in the Launceston basin, covering an area of at least 600 square miles. This series encloses a rich flora, including species of oak, elm, beech, laurel, cinnamon, and araucaria, with fruits of proteaceous, sapindaceous, and coniferous trees. The fresh-water and terrestrial character of the deposits is further confirmed by the occurrence in them of *Unio*, *Helix*, *Vitrina*, *Bulimus*, &c. The third group in descending order is of marine origin, and is well seen at Table Cape. It consists of shelly limestones, calcareous sandstones, coral-rag, and pebbly bands, and is replete with fossils, only from 1 to 3 per cent of the shells belonging to existing species. Characteristic forms are *Voluta anticingulata*, *Cassis*

[1] Duncan, *Q. J. G. S.* 1870, p. 313. See also papers by A. C. R. Selwyn, "Report on Geology of Melbourne," &c., *Parl. Papers*, 1854-55; 'Exhibition Essays,' 1866. J. E. Tennison Woods, *Q. J. G. S.* xvi. p. 253; *Proc. Roy. Soc. Tasmania*, 1876, p. 92. F. M'Coy, 'Exhibition Essays,' 1861, p. 159. G. B. Pritchard, *Australasian Assoc.* 1895; "On Tertiaries of Australia, with Catalogue of Fossils," Adelaide Technological Museum, 1892; and joint papers with Mr. T. S. Hall in *Proc. Roy. Soc. Victoria* from 1893 onwards.

sufflatus, *Cypræa Archeri*, *Ancilla mucronata*, *Panopæa Agnewi*, *Waldheimia garibaldiana*, *Lovenia Forbesi*, *Cellepora gambierensis*.[1]

In New Zealand, rocks believed by Sir James Hector to be partly a Cretaceo-Tertiary series are mainly composed of a shelly calcareous sandstone with corals and polyzoa, which in its lower part passes occasionally into an imperfect nummulitic limestone (Nummulitic beds, Hutchison's Quarry beds, Mount Brown beds). Volcanic action was greatly developed during the deposit of these strata in both islands. Hence interbedded lavas and tuffs are frequent, and in the North Island the calcareous deposits are often wholly replaced by wide-spread trachyte-flows and volcanic breccias.[2]

Captain Hutton has proposed a separation of the younger deposits of the colony into three formations: 1st, Waipara (Cretaceo-Tertiary of the Geological Survey, now regarded by him as probably Upper Cretaceous), consisting of argillaceous limestone and calcareous sandstone, underlain by marl and other sandstones with a maximum thickness of about 1200 or 1300 feet; the lower strata contain brown-coal, and among the plants are *Araucaria*, *Flabellaria*, *Cinnamomum*, and a number of genera still living in New Zealand, such as *Panax*, *Loranthus*, *Fagus*, *Dammara*, *Podocarpus*, *Dacrydium*. Higher up come marine sediments, enclosing species of *Ostrea*, *Pecten*, *Perna*, *Tellina*, *Trigonia*, *Inoceramus*, Belemnites, Ammonites, Scaphites, together with remains of fishes (*Myliobatis*) and marine saurians (*Cimoliosaurus*, *Polycotylus*, *Leiodon*). During the deposition of the older rocks of this division volcanic activity showed itself along the western margin of the Canterbury plains, the earliest eruptions consisting of rhyolite followed by dolerite and basalt. 2nd, Oamaru (Upper Eocene of Survey), regarded by Captain Hutton as Oligocene (*postea*, p. 1261); and 3rd, Pareora (Lower Miocene of Survey) considered by him to be Miocene (p. 1274).[3]

Section ii. Oligocene.

§ 1. General Characters.

The term "Oligocene" was proposed in 1854 and again in 1858 by Beyrich[4] to include a group of strata distinguishable from the Eocene formations of France and Belgium, and which Lyell had classed as "Older Miocene." They consist partly of terrestrial, partly of fresh-water and brackish, and partly of marine strata, indicating considerable oscillations of level in the European area. They consequently present none of the massive deep-water characters so conspicuous in some of the Eocene subdivisions. Among other geographical changes of which they preserve the chronicles is the evidence of the gradual conversion of portions of the sea-floor over the heart of Europe into wide lake-basins in which thick lacustrine deposits were accumulated. Some of these lakes did not attain their fullest development until the Miocene period.

The Oligocene flora, according to Heer, is composed mainly of an

[1] Mr. R. M. Johnston, Registrar-General at Hobart, Tasmania, 'Observations with respect to the Nature and Classification of the Tertiary Rocks of Australasia' (1888), and his important volume, 'A Systematic Account of the Geology of Tasmania,' 1888, pp. 208-295, where much information is also given regarding the geology of the other Australasian colonies.

[2] Hector's 'Handbook of New Zealand,' p. 28.

[3] *Trans. New Zealand Inst.* xix. (1886), p. 392; xxxii. (1899), p. 168.

[4] *Monatsbericht. Akad. Berlin*, 1854, pp. 640-666; 1858, p. 51.

evergreen vegetation, and has characters linking it with the living tropical floras of India and Australia and with the subtropical flora of America. It includes some ferns, fan-palms, and feather-palms (*Sabal*, *Phœnicites*), a number of conifers (*Sequoia*, &c., Fig. 469), cinnamon-trees, evergreen

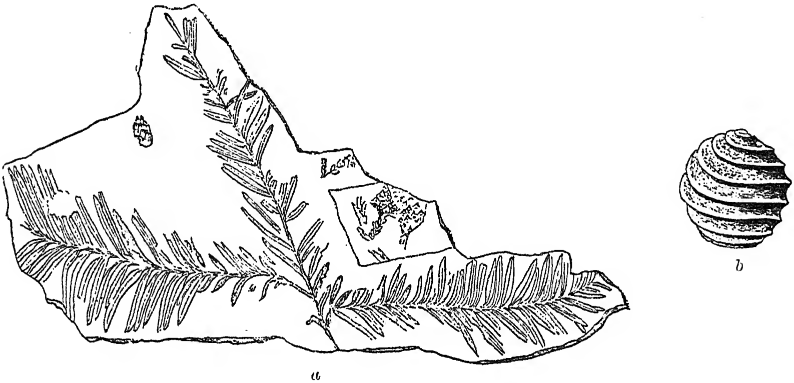

Fig. 469.—Oligocene Plants.
a, Sequoia Langsdorfii, Brongn. (½) (from Heer's 'Flor. Tert. Helvetiæ,' i. pl. 21);
b, Chara Lyellii, Forbes (10/1).

oaks, custard-apples, gum-trees, spindle-trees, oaks, figs, laurels, willows, vines, and proteaceous shrubs (*Dryandra*, *Dryandroides*).

The fauna displays a distinct advance on that of the previous period, and a nearer approach to that of the present day. The nummulites, though they no longer play the important part which they did in Eocene times, continue abundant in the southern regions of Europe, but rapidly

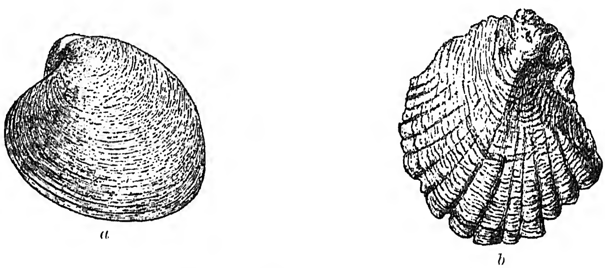

Fig. 470.—Oligocene Lamellibranchs.
a, Meretrix (Cytherea) incrassata, Sow. (2/3); b, Ostrea cyathula, Lam. (2/3).

diminish in number and variety after the close of the Oligocene period. Coral-reefs may still be traced along the flanks of the mountain chain from the Pyrenees to the eastern Alps. The existing families of crinoids and sea-urchins have their representatives in the Oligocene fauna. Bryozoa are found in great profusion in the deposits of this period in North Germany. Among the Oligocene mollusca (Figs. 470, 471) some of the more important genera are *Ostrea*, *Pecten*, *Nucula*,

Cardium, *Meretrix* (*Cytherea*), *Corbicula*, *Cancellaria*, *Murex*, *Fusus*, *Typhis*, *Pleurotoma*, *Volutilithes*, *Cerithium*, *Potamides*, *Melania*, *Planorbis*.[1]

As a notable portion of the Oligocene series, both in the Old and the New World, consists of the deposits of lake basins, the fauna of the land has been preserved more fully than among the other older Tertiary formations. Especially remarkable is the variety of insect life which has in this way been recorded. The most striking example of this variety and abundance is supplied by the small basin of Florissant in Southern Colorado, from which Mr. Scudder has obtained more than 1300 species, which embrace representatives of all the great divisions of insect life, including upwards of 30 species of spiders. Some idea may be formed of the richness of these strata from the fact that up to the year 1885 they had furnished more than 4000 specimens of ants. They have also supplied remains of birds, including even the feathers, together with relics of the flora of the surrounding land, and of the fishes that tenanted the lake.[2] From the deposits left by the lakes in Central France we obtain a glimpse of

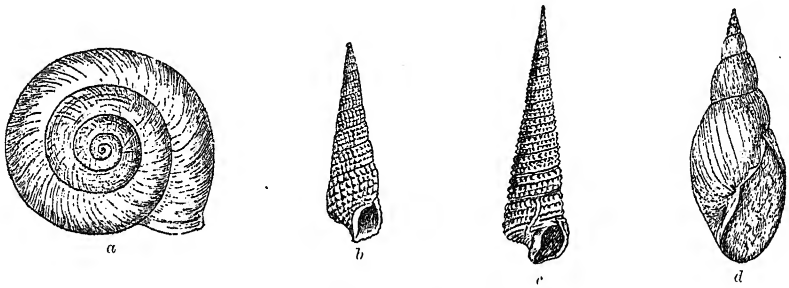

Fig. 471.—Oligocene Gasteropods.

a, Planorbis euomphalus, Sow. ($\frac{2}{3}$); *b*, Potamides (Granulolabium) plicatus, Lam. ($\frac{2}{3}$); *c*, Potamides cinctus, Sow. ($\frac{2}{3}$); *d*, Limnæa longiscata, Brongn. ($\frac{2}{3}$).

the varied bird life of that region in Oligocene time. Thus from the lacustrine beds of the Department of the Allier no fewer than 66 species had been obtained previous to the year 1871, comprising parroquets, trogons, flamingoes, ibises, pelicans, marabouts, cranes, secretary-birds, eagles, grouse, and numerous gallinaceous birds—a fauna which reminds us of that of the lakes in Southern Africa.[3]

It is the mammalian portion of the fauna, however, which claims chief attention as evidence of the biological advance of the period. It shows a continual increase in variety of forms. According to Gaudry the following chronological sequence of appearances and disappearances during the Oligocene period have been noted in Europe.[4]—

[1] For a list of British Oligocene mollusca, see Mr. R. B. Newton's volume cited on p. 1226.

[2] *B. U.S. G. S.* No. 93 (1892).

[3] A. Milne-Edwards, 'Oiseaux Fossils de la France,' 1867-71; Boyd Dawkins, 'Early Man in Britain,' p. 54.

[4] 'Les Enchaînements du Monde Animal,' 1878, p. 4. Compare the table, *postea*, p. 1260.

3rd Stage (Aquitanian).—St. Gérand-le-Puy (Allier), Calcaire de Beauce in part.	Appearance of the genera *Rhinoceros* (?), *Tapirus*, *Palæochœrus*, shrew, *Plesiosorex*, *Mysarachne*, mole, musk-rat, *Potamotherium*, *Palæonycteris*. The ruminants are as yet without horns; the proboscidians have not yet appeared.
2nd Stage (Stampian).—Fontainebleau Sands, Ferté-Alais (Seine-et-Oise).	Appearance of the genus *Tetracus*. Disappearance of *Palæotherium* and *Anoplotherium*. Reign of *Hyopotamus* and *Anthracotherium*.
1st Stage (Infra-Tongrian, Sannoisian).—Calcaire de Brie, &c.	Appearance of the genera *Cadurcotherium*, *Hyrachyus* (an American genus), *Entelodon*, *Anthracotherium*, *Dacrytherium*, *Chalicotherium*, *Tragulohyus*, *Lophiomeryx*, *Hyæmoschus* (?) *Gelocus*, *Dremotherium*, *Thereutherium*, dog (?), civet, marten, *Plesictis*, *Palæogale*, *Ælurictys*, *Rhinolophus*, *Necrolemur*.

The White River series of deposits in Dakota and other interior States of America (p. 1260) have furnished an abundant series of mammalian vertebrates, which continues and increases the astonishment with which the Eocene treasures of the West have filled geologists and comparative anatomists. The long list of fossils includes a number of marsupials closely allied to the living American opossums (*Didelphys*); rodents, including *Ischyromys*, *Sciurus*, *Gymnoptychus*, *Eumys*, several beavers (*Steneofiber*), and some hares (*Palæolagus*). The creodonts were represented around those western lakes by several species of *Hyænodon*, the carnivores by canidæ (*Daphænos* or *Amphicyon*, *Cynodictis*), weasels (*Bunælurus* or *Palæogale*), felidæ (*Dinictis*, *Hoplophoneus* or *Drepanodon*, *Eusmilus*). There were likewise insectivores (*Ictops*), horses (*Mesohippus* or *Anchitherium*, *Anchippus*), lophiodonts (*Colodon*), tapirs (*Protapirus*), rhinoceroses (*Leptaceratherium*, *Aceratherium*, *Hyracodon*, *Metamynodon*), the gigantic rhinoceros-like *Titanotherium*, of which nearly 30 species have been determined,[1] artiodactyl ungulates (*Hyopotamus*, *Elotherium*), primitive ruminants (*Agriochœrus*, *Oreodon*, *Eporeodon*, *Mesoreodon*, *Leptauchenia*, camels of the genera *Pöebrotherium* and *Protomeryx*, &c., tragulidæ or chevrotains of the genera *Leptomeryx*, *Hypertragulus*, *Hypisodus*, and representatives of the allied family of protoceratidæ (*Protoceras*).

§ 2. Local Development.

Britain.—Oligocene strata are confined to one small area in this country. They occur in the Hampshire basin and Isle of Wight, where, resting conformably upon the top of the Eocene deposits, they consist of sands, clays, marls, and limestones, in thin-bedded alternations. They were accumulated partly in the sea, partly in brackish, and partly in fresh water. They were hence named by Edward Forbes "the fluvio-marine series," and were divided by him and W. H. Bristow into the following groups in descending order :[2]—

[1] H. F. Osborn, *Bull. Amer. Mus. Nat. Hist.* viii. (1896), p. 174. This observer has shown that the genera *Symborodon*, *Diconodon*, *Brontops*, *Titanops*, *Allops*, *Haplacodon* and *Diploconus* have been founded on differences of character arising from marks of sex, age or individual variability, and have no standing, all the forms designated by them being referable to *Titanotherium*. The American sequence of mammals is given, *postea*, p. 1260.

[2] "Geology of the Isle of Wight," *Mem. Geol. Survey*, 2nd edit. (1889), p. 124. The grouping as there given has been slightly modified by Mr. C. Reid in the course of a re-survey of the Isle of Wight. The strata were formerly regarded as Upper Eocene.

Hamstead Beds.—(*b*) Marine stage with *Corbula*, *Meretrix* (*Cytherea*), *Ostrea callifera*, *Volutilithes*, *Natica*, *Potamides*, and *Melania* . .	31 ft.
(*a*) Fresh-water, estuarine, and lagoon stage, with *Unio*, *Corbicula*, *Sphærium*, *Viviparus*, *Stenothyra*, *Melanopsis*, *Planorbis*, *Potamides* (rare), turtles, crocodiles, mammals, leaves, and seeds . . .	225 ,,
Bembridge Beds.—(*b*) Bembridge marls—a fresh-water, estuarine, and marine series of clays and marls, with *Viviparus*, *Melania*, *Melanopsis*, *Limnæa*, *Corbicula*, *Unio*, *Ostrea*, *Meretrix*, *Dreissensia*, *Nucula*	70-120 ,,
(*a*) Bembridge Limestone—full of fresh-water shells (*Limnæa*, *Planorbis*, &c.), and sometimes with many land-shells (*Amphidromus*, *Glandina*, *Helix*, &c.)	15-25 ,,
Osborne Beds.—Marls, clays, shales, and limestones, with *Limnæa*, *Planorbis*, *Viviparus*, *Melanopsis*, *Melania*, *Chara*, &c. . .	80-110 ,,
Headon Beds.—(*c*) Upper stage, consisting of fresh-water clays, marls, and bands of limestone, with *Erodona* (*Potamomya*), *Limnæa*, *Corbicula*, *Unio*, *Planorbis*, *Viviparus*, *Melanopsis*, &c.	40-60 ,,
(*b*) Middle stage, clays, sands, loams, and limestone, with brackish-water and marine fossils (*Potamides*, *Melania*, *Natica*, *Neritina*, *Pisania*, *Ancilla*, *Meretrix* (*Cytherea*), *Psammobia*, *Ostrea*, *Corbicula*, &c.)	30-126 ,,
(*a*) Lower stage, marls, clays, sandstones, and tufaceous limestones with fresh- and brackish-water shells (*Limnæa*, *Viviparus*, *Planorbis*, *Corbicula* (*Potamomya*), &c.)	60-157 ,,

A large number of the marine mollusca of the Headon Beds range downwards into the Barton Clay, but about half are peculiar to the Oligocene series. Among the more abundant forms in the Isle of Wight are *Meretrix* (*Cytherea*) *incrassata*, *Ostrea velata*, *O. flabellula*, *Nucula headonensis*, *Potamides* (*Batillaria*) *concavus*, *Melanopsis fusiformis*, *Pisania labiata*, *Murex sexdentatus*, *Neritina aperta*, *N. concava*, *Ancilla buccinoides*, *Melania muricata*, and several species of *Cancellaria*, *Natica*, *Pleurotoma*, and *Volutilithes*, with *Balanus unguiformis*. The estuarine and fresh-water strata are marked by species of *Erodona* (*Potamomya*) and *Corbicula*, while the purely fresh-water deposits are full chiefly of Limnæids belonging to the genera *Limnæa* and *Planorbis*, *L. longiscata* and *P. euomphalus* being perhaps the most abundant and conspicuous species; *Viviparus* (*Paludina*) *lentus* is also plentiful. Mr. Reid has remarked that every variation in the salinity of the water seems to have affected the molluscan fauna of the estuary in which these deposits were accumulated. When the water was quite fresh the pond snails flourished in abundance, and their remains were mingled with those of *Unio* and *Helix*. The gradual inroad of salt water is marked by the advent of *Erodona* (*Potamomya*), *Corbicula*, *Potamides*, *Melania*, and *Melanopsis*, while the thoroughly marine fauna with volutes and cones shows when the sea had entirely replaced the fresh water.[1]

The Bembridge Limestone, one of the most conspicuous members of the Oligocene series in the Isle of Wight, is a remarkable example of a fresh-water limestone, full of fresh-water and terrestrial shells and nucules of *Chara*. The land-shells comprise tropical-looking gigantic species of *Amphidromus* (*A. ellipticus*) and *Glandina* (*G. costellata*). An interesting feature in the overlying Bembridge marls is the occurrence of a thin band from two inches to two feet in thickness of a fine-grained limestone like lithographic stone, containing many insect-remains together with leaves and fresh-water shells. Some twenty genera of insects have been detected in it, including forms of coleoptera, hymenoptera, lepidoptera, diptera, neuroptera, orthoptera, and hemiptera.[2]

The Hamstead (formerly *Hempstead*) beds form an interesting close to the Oligocene series. They consist chiefly of fresh-water, estuarine, and lagoon deposits. But they pass upward into a group of marine strata of which, owing to denudation, only about 30 feet are now visible. Among the more abundant or peculiar of the shells in this

[1] C. Reid, 'Geology of the Isle of Wight,' p. 147.

[2] H. Woodward, *Q. J. G. S.* xxxv. p. 342; C. Reid, 'Geology of the Isle of Wight,' p. 177.

marine band the following may be mentioned :—*Ostrea callifera, O. adlata* (both peculiar), *Meretrix* (*Cytherea*) *Lyellii, Corbula pisum, C. vectensis, Cuma monoplex, Volutilithes Rathieri, Potamides plicatus, P. Sedgwickii, Strebloceras cornuoides.*[1]

Considerable interest attaches to the marine band forming the middle division of the Headon beds, as it serves for a basis of correlation between the English strata and their equivalents on the Continent. This band, so well seen in the Isle of Wight, occurs also at Brockenhurst and other places in the New Forest. It has yielded more than 230 species of fossils, almost all marine mollusks, but including also 14 species of corals. Of these organisms, a considerable proportion is common to the Lower Oligocene of France, Belgium, and Germany, and 22 species are found in the Upper Bagshot beds.[2]

The Oligocene or fluvio-marine series of the Hampshire basin has likewise yielded vertebrate remains such as characterise the corresponding deposits of the Continent. They include those of rays (*Myliobatis*), snakes (*Paleryx*), crocodiles, alligators, turtles (*Ocadia, Trionyx*, numerous species) and a cetacean (*Balænoptera ?*); while from the Bembridge beds have come the bones of a number of the characteristic mammals (*Anchilophus, Anthracotherium, Anoplotherium*, two species, *Palæotherium*, six or more species, *Chœropotamus, Dichodon*). The top of the fluvio-marine series in the Isle of Wight having been removed in denudation, the records of the rest of the Oligocene period have there entirely disappeared.

For many years it was customary to consider as Miocene certain plant-bearing strata, of which a small detached basin occurs at Bovey Tracey, Devonshire, but which are mainly distributed in the great volcanic plateaux of Antrim and the west of Scotland. These strata have subsequently been regarded as equivalents of the Oligocene formations on the Continent. At the Bovey Tracey locality, which is not more than 80 miles from the Eocene leaf-beds of Bournemouth and the Isle of Wight, a small but interesting group of sand, clay, and lignite beds, from 200 to 300 feet thick, lies between the granite of Dartmoor and the greensand hills, in what was evidently the hollow of a lake. From these beds, Heer of Zurich, who has thrown so much light on the Tertiary floras of both the Old World and the New, described about 50 species of plants, which, in his opinion, place this Devonshire group of strata on the same geological horizon with some part of the Molasse or Oligocene (Lower Miocene) groups of Switzerland. Among the species are a number of ferns (*Lastræa stiriaca, Pecopteris* (*Osmunda*) *lignitum*, &c.) ; some conifers, particularly *Sequoia Couttsiæ*, the matted débris of which forms one of the lignite beds ; cinnamon-trees, evergreen oaks, custard-apples, eucalyptus, spindle-trees, a few grasses, water-lilies, and a palm (*Palmacites*). Leaves of oaks, figs, laurels, willows, and seeds of grapes have also been detected—the whole vegetation implying a subtropical climate.[3] Subsequently Mr. Starkie Gardner expressed the opinion that this flora is on the same horizon as that of Bournemouth, that is, in the Middle Eocene group.[4] Mr. Clement Reid, also, has expressed the opinion that "the resemblance of the deposits and of their flora to the undoubted Bagshot [Beds] of Dorset is most striking. Still one cannot say that the botanical evidence is conclusive, for the species are few and greatly need re-examination. Other

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[1] C. Reid, *op. cit.* p. 206.

[2] A. von Könen, *Q. J. G. S.* xx. (1864), p. 97. Duncan, *op. cit.* xxvi. (1870), p. 66. J. W. Judd, *op. cit.* xxxvi. (1880), p. 137 ; xxxviii. (1882), p. 461. H. Keeping and E. B. Tawney, *op. cit.* xxxvii. (1881), p. 85 ; xxxix. (1883), p. 566. E. B. Tawney, *Geol. Mag.* 1883, p. 157. W. Keeping, *Geol. Mag.* 1883, p. 428. J. W. Elwes, *Brit. Assoc.* 1882. Sects. p. 539.

[3] *Phil. Trans.* 1862.

[4] "British Eocene Flora," *Palæont. Soc.* 1879, p. 18. See also *Q. J. G. S.* xli. p. 82. The uncertainty hitherto experienced in the correlation of deposits by means of land-plants has been already referred to (pp. 832, 839, 848, 1034).

fossils are almost entirely absent."[1] If this view be ultimately established, the volcanic rocks of the north-west of Britain, with their leaf-beds, may be also relegated to the Eocene period. In the meantime, however, these various plant-bearing deposits are retained here in the Oligocene series as possibly equivalents of the brown-coal and molasse of the Continent.

The plateaux of Antrim, Mull, Skye, and adjacent islands are composed of successive outpourings of basalt, which are prolonged through the Faroe Islands into Iceland, and even far up into Arctic Greenland. In Antrim, where the great basalt sheets attain a thickness of 1200 feet, there occurs in them an intercalated band about 30 feet thick, consisting of tuffs, clays, thin conglomerate, pisolitic iron-ore, and thin lignites. Some of these layers are full of leaves and fruits of terrestrial plants, with occasional insect-remains. According to the data collected by a Committee of the British Association, upwards of thirty species of plants have been obtained, including conifers (*Cupressinoxylon, Taxodium, Sequoia, Pinus*), monocotyledons (*Phragmites, Poacites, Iris*), dicotyledons (*Salix, Populus, Alnus, Corylus, Quercus, Fagus* (?), *Platanus, Sassafras, Acer, Andromeda, Viburnum, Aralia, Nyssa, Magnolia, Rhamnus, Juglans*, &c.).[2] In the west of Scotland the volcanic sheets attain still greater dimensions, reaching in Mull a thickness of 3000 feet, and there also including thin tuffs, leaf-beds, and coals. In Mull, Skye, and Antrim the terraces of basalt, with occasional comparatively thin bands of tuff and sheets of rhyolitic and trachytic lavas, form a noble example of the extravasation of great piles of molten material without the formation of central cones or the discharge of much fragmentary matter (p. 345). They have been invaded by huge bosses of gabbro and of various granitoid rocks, which send veins into and alter the basalt. They are likewise traversed by veins of pitchstone, but more especially by prodigious numbers of basalt-dykes, which in Scotland have a prevalent W.N.W. and E.S.E. direction. The basalt-plain was channelled by rivers, and into the ravines thus eroded streams of pitchstone made their way (Scuir of Eigg), whence it is evident that the volcanic eruptions lasted during a protracted period.[3]

France.—In the Paris basin, where a perfect upward passage is traceable from Eocene into Oligocene beds, the latter are composed of the following subdivisions:[4]—

Aquitanian. { Calcaire de la Beauce—a lacustrine deposit, is separable into a higher assise (Molasse du Gâtinais, sometimes 57 feet) consisting of green marl, siliceous sand, and calcareous sandstone passing into the Helix limestone of the Orléanais (*Helix Moroguesi, H. aurelianus, H. Tristani, Planorbis solidus, Limnæa Larteti, Melania aquitanica*, &c.); and a lower, composed of limestone (Calcaire du Gâtinais with *Limnæa Brongniarti, L. cornea, L.*

[1] *Q. J. G. S.* lii. (1896), p. 490, and liv. (1898), p. 234.

[2] W. H. Baily, *Brit. Assoc.* 1879, Rep. p. 162; 1880, p. 107; 1881, p. 152; J. Starkie Gardner, *Q. J. G. S.* xli. p. 82; xliii. p. 270. On the north coast of Antrim, near Ballintoy, a band of tuff occurs about 150 feet thick. But in Ireland, as in Scotland, the tuffs take quite a subordinate place among the great piles of basalt.

[3] A. G., *Proc. Roy. Soc. Edin.* vi. (1867), p. 71; *Q. J. G. S.* xxvii. (1871), p. 280; xlviii. (1892), Pres. Address, p. 162; l. (1894), pp. 212, 645; lii. (1896), pp. 331-405; 'Ancient Volcanoes of Great Britain,' 1867, vol. ii.; *Trans. Roy. Soc. Edin.* xxxv. (1888), p. 21. Professor Judd (*Q. J. G. S.* xxx. (1874), p. 220; xlv. (1889), p. 187; xlix. (1893), p. 175) supposed that there were five great volcanic cones in the Western Islands whence the streams of basalt flowed, and of which the mountains of Mull, Skye, &c. are the degraded ruins, and he regarded the granitoid rocks as older than the others. The true order of succession as established by me has been completely demonstrated by the recent detailed examination of the ground by Mr. Harker of the Geological Survey, *Summary of Progress of Geol. Surv.* for 1897, 1898, 1899, 1900; *Geol. Mag.* 1901, p. 506.

[4] Dollfus, *B. S. G. F.* 3e sér. vi. (1878), p. 293. A. De Lapparent, 'Traité,' 4th edit. 1900. The separation of an Oligocene series in the Paris basin is not admitted by some French geologists.

cylindrica, *Helix Ramondi*, *Cyclostoma antiquum*, *Planorbis cornu*, *Potamides Lamarcki*, and a number of mammals, including *Anthracotherium*, *Aceratherium*, *Rhinoceros*, &c.

Stampian.

Sables et Grès de Fontainebleau and other places. In the Étampes district, where these deposits are well developed, they reach a thickness of about 130 feet. At their top lies the Ormoy Sand, which has been indurated by a siliceous cement and furnishes hard paving-stones. The fauna on the whole is marine, as is shown by its including species of *Buccinum*, *Pleurotoma*, *Cerithium*, *Natica*, *Cassidaria*, *Meretrix incrassata*.

Oyster-marls with *Ostrea longirostris*, *O. cyathula*, and *Corbula subpisum* forming an important water-bearing horizon below the thick overlying sands. These marls pass into the Molasse d'Étrechy with *Potamides plicatus*, *Bayania semidecussata*, *Meretrix incrassata*, &c.

Tongrian (Sannoisian).

Calcaire de la Brie, a lacustrine limestone with few fossils, *Limnæa cornea*, *Planorbis cornu*, *Chara*, &c.

Green-Marls (Marnes à Cyrènes, glaises vertes), consisting of an upper mass of non-fossiliferous clay, and a lower group of fossiliferous laminated marls (*Potamides plicatus*, *Psammobia plana*, *Corbicula semistriata = convexa*).

Supra-gypseous blue marls, with very few fossils (*Nystia plicata*). White marls (Marnes de Pantin), with *Limnæa strigosa*, *Planorbis planulatus*, *Bithinia* (*Nystia*) *Duchasteli*.

Geographical names have been assigned to the subdivisions of the Oligocene series in France, Belgium, Switzerland, and North Italy. The lowest member is called Tongrian, from Tongres, in Limbourg.[1] Above it comes the Stampian, so named from Étampes, where it is typically developed. The uppermost group is known as Aquitanian, from its well-marked occurrence in Aquitania.

The chief area of Oligocene strata in France lies in the Paris basin between Epernay and Saumur, where, spreading over a wide extent of country, they have been cut down by the streams so as to reveal the Eocene formations below them. The next tract in importance lies far to the south-west (Aquitania), where the Lower Oligocene division consists of a group of strata alternately marine and fresh-water.[2] At the bottom lies a band of marls with *Anomia* and *Ostrea*, which graduates upward into molasse and limestone (Castillon, Civrac) containing lacustrine shells, and possibly equivalent to the Calcaire de la Brie of the Paris basin. Next comes a thoroughly marine band in the form of a limestone full of remains of star-fishes, together with species of *Natica*, *Cerithium*, *Trochus*, &c., but passing laterally into fresh-water deposits. The highest or Aquitanian division includes a series of "faluns," or limestones, marls, and sandstones, partly marine and partly lacustrine. The marine bands are marked by the presence of *Ostrea aginensis*, *Lucina scopulorum*, *Arca cardiiformis*, *Turritella Desmaresti*, *Cerithium calculosum*, *C. bidentatum*, *C. fallax*, *C. margaritaceum*, *Pyrula Lainei*. The lake deposits, in addition to fresh-water and land shells, enclose remains of land-plants as well as bones of the terrestrial mammals of the time. Similar alternations of sedimentary conditions may be traced eastwards through Languedoc and the Ardèche into Provence, where lacustrine deposits (*Physa*, *Planorbis*, *Limnæa*) lie immediately upon the Upper Cretaceous rocks. At Aix these beds have long been noted for their abundant plants (*Callitris Brongniarti*, *Widdringtonia brachyphylla*, *Flabellaria lamanonis*, *Quercus*, *Laurus*, *Cinnamomum*), insects and mammals (*Palæotherium*, *Xiphodon*, *Anoplotherium*, *Chœropotamus*). In Dauphiné the Upper Oligocene division is represented by from 800 to 900 feet of marls and limestone-bands, with *Melania* and *Corbicula*, and capped by limestones containing land or fresh-water shells. Still farther east the Oligocene passes into the Flysch of the Alps.

The brackish waters in which the deposits of the lower division of the Oligocene series

[1] Professor De Lapparent, instead of this term, proposed originally by Dumont, has adopted "Sannoisian," from Sannois, near Paris.

[2] A detailed account of the Tongrian stage in Aquitania has been given by Professor Fallot of Bordeaux, *Mém. Soc. Sci. Phys. Nat. Bordeaux*, 4e sér. v. (1894).

in the Paris basin were laid down seem to have stretched southward into the Plateau Central. That region had long been a terrestrial surface on which a crust of weathered material (laterite) had accumulated. In the hollows of this surface, marls and limestones were deposited, containing *Cerithium margaritaceum* and species of *Potamides* and *Corbicula*. By degrees there arose a lake or group of lakes, in the sediments of which have been abundantly preserved the relics of the lacustrine fauna as well as of the plants and animals of the surrounding land. In the largest of these lakes, that of the Limagne d'Auvergne, a thick series of arkoses, marls, and limestones accumulated. In this mass of strata representatives of the three divisions of the Oligocene series have been recognised. Towards the north the middle or Stampian group rests directly on the granite, but southwards the lower or Sannoisian appears from underneath and expands until it constitutes there the greater part of the whole succession. It marks the spread of brackish water lagoons over the region. The Stampian strata, which comprise the main part of the Oligocene history of the Limagne, reach a thickness which may perhaps exceed 1000 metres (3280 feet). They consist of marls, limestones, and sandstones, the limestones formed of the remains of lacustrine and land-shells (*Limnæa*, *Nystia*, *Hydrobia*, *Helix*), cyprids, oogonia of *Chara*, and in some instances the crowded cases of caddis-worms (*Phryganea*), which were constructed of young univalve shells. In the lower part of the Stampian group are found *Gelocus*, *Anthracotherium*, *Hyænodon*, *Peratherium*; in the middle comes *Lophiomeryx*, and in the upper *Dremotherium* and *Cænotherium*. The portion of the series referred to the Aquitanian stage is comparatively feebly represented in the Limagne, the best development being seen in the upper marls and plant-bearing sands of the well-known Hill of Gergovia, south of Clermont Ferrand. From the phrygania-limestones and marls of this division, however, an extraordinarily abundant and varied vertebrate fauna has been obtained in the district of Gérand-le-Puy. Upwards of 50 species of mammals, about 70 of birds, 11 of reptiles, 2 of amphibians, have been named by MM. Filhol, Pomel, and Milne-Edwards. The mammals include a bat (*Palæonycteris*), a hedgehog (*Palæoerinaceus*), various rodents like our modern dormice, marmots, and beavers (*Myoxus*, *Titanomys*, *Sciurus*, *Steneofiber*); a large number of carnivores (*Lutra*, *Amphicyon*, *Cephalogale*, *Plesictis*, *Viverra*, *Herpestes*, *Amphictis*, *Mustela*, *Proælurus*); ungulates (*Chalicotherium*, *Cænotherium*, *Plesiomeryx*, *Aceratherium*, *Rhinoceros*, *Protapirus*, *Hyotherium*, *Dremotherium*, *Amphitragulus*); and an opossum (*Amphiperatherium*). The birds comprise parrots (*Psittacus*), eagles, kites (*Milvus*), owls (*Bubo*, *Strix*), wagtails (*Motacilla*), trogons, woodpeckers (*Picus*), pigeons (*Columba*, *Pterocles*), gallinaceous forms (*Palæortyx*), rails (*Rallus*), flamingoes (*Phœnicopterus*), cranes (*Grus*), herons (*Ardea*), storks (*Argala*), ibises, redshanks (*Totanus*), dunlins (*Tringa*), shearwaters (*Puffinus*), gulls (*Larus*), cormorants (*Phalacrocorax*), gannets (*Sula*), pelicans, and ducks (*Anas*). Among the reptiles are species of *Testudo*, *Ptychogaster*, *Chelydra*, and *Trionyx*.[1] M. Milne-Edwards called attention to the remarkable resemblance of this avian assemblage to that characteristic of the great lake-basins of Central Africa. It may be added that an additional feature of interest in the old lakes of the Limagne is presented by the abundant intercalation of seams and partings of fine basalt-tuff interstratified among the marls and limestones, which show that the volcanic history of that region goes back into Oligocene time.[2]

[1] H. Filhol, *Ann. Sci. Géol.* x. (1879); xi. (1880); xii. (1882); A. Milne-Edwards, 'Recherches anatomiques et paléontologiques pour servir à l'histoire des oiseaux fossiles de la France,' 4 vols. 4to, Paris, 1867-71.

[2] These intercalations of tuff form the "Peperites" of Auvergne, regarding which so much difference of opinion has been expressed. Some geologists, impressed by the proofs of intrusion by the peperites in certain places, have come to the conclusion that these tuffs are everywhere intrusive, and that their obvious interstratification in thin leaves among the undisturbed lacustrine strata is to be explained by some [unintelligible] process of transfusion.

In the east and centre of France a peculiar ferruginous deposit (Terrain sidérolithique) is traceable over a wide region, sometimes forming the surface and sometimes passing under younger Tertiary formations. It consists of an earth or clay full of pisolitic grains of limonite, which are often in sufficient quantity to afford a workable source of iron. With it are associated sheets of limestone or travertine full of remains of *Chara* and fresh-water or land shells. Where these deposits lie on Jurassic limestones they fill up fissures and cavities of the older rock, and, like the Eocene osseous breccias already noticed, have entombed and preserved remains of the contemporary terrestrial fauna. In some places these remains have accumulated in such quantity as to furnish valuable deposits of phosphate of lime. Such are the phosphorites of Quercy, which have filled up fissures and pockets in the limestones. The upper part of the deposits generally consists in large part of red clay and loam full of granular limonite, while the lower portions are phosphatic. There appears to be always a close relation between these accumulations and Tertiary strata in their vicinity, and they are never found on the higher limestone plateaux above the level of these strata. The Quercy phosphorites are famous for the variety of animal remains yielded by them, which number 58 genera of mammals, whereof 25 have been found in the Paris gypsum. They include artiodactyle ungulates (*Anoplotherium*, *Anthracotherium*, *Amphitragulus*, *Cænotherium*, *Xiphodon*), perissodactyle ungulates (*Lophiodon*), pig-like animals (*Cebochœrus*), a rhinoceros (*Aceratherium*), carnivores (*Cynodictys*, *Hyænodon*), and lemuroid monkeys (*Adapis*, *Necrolemur*).[1]

Belgium.[2]—The Oligocene succession in this country differs from that of France, and has received a different nomenclature, as follows:—

Upper Oligocene wanting in Belgium in the form of marine deposits; represented in Upper Belgium by sands and gravels, sometimes indurated into sandstones and conglomerates, and—

Rupelian.
- Upper.
  - White fine sands.
  - Clay of Boom containing more than 60 species of shells (*Murex Deshayesi*, *Typhis Schlotheimi*, *Fusus elatior*, *Cassidaria nodosa*, *Pleurotoma Duchasteli*, *Voluta fusus*, *Mitra Delpeidi*, *Pectunculus obovatus*, *Nuculana Deshayesiana*, *Corbula striata*, *Terebratulina striatula*), a number of fishes, both teleostean and elasmobranch (*Cybium*, *Dictyodus*, *Scombramphodon*, *Labrax*, *Carcharodon*, *Lamna*, *Odontaspis*, *Oxyrhina*, *Myliobatis*, *Galeocerdo*, *Chimæra*, *Squatina*), some chelonians, birds (*Anas*, *Larus*), and sirenian mammals (*Crassitherium*, *Halitherium*, *Metaxytherium*).
- Sands and gravels.
- Clay with *Nucula compta*.

The phenomena are easily understood, however, by one who has made himself familiar with the behaviour of tuffs in an ancient dissected volcanic region like that of Central Scotland (p. 175). The material of the peperites has undoubtedly here and there filled up the volcanic vents, and has even been injected in veins and dykes around their margins. But the main mass of the material was ejected from these vents, and falling, as volcanic dust and sand, over the lake and surrounding ground, became interleaved with the contemporaneous lacustrine sediments, thus affording the most satisfactory evidence that the long series of volcanic eruptions in Auvergne began as far back as upper Oligocene time. The most recent presentation of the arguments for the intrusive nature of the material will be found in No. 87 of the *Bull. Carte Géol. France* (1902), by J. Giraud, where the fullest account of the formations is given, together with a useful bibliography. Professor Gosselet clearly recognised the impossibility of accounting for the tranquil interstratification of the fine material of the tuff among the unbroken shells of the *Helix*-limestone by any process other than that of contemporaneous deposition, *B. S. G. F.* xviii. (1890), p. 913.

[1] H. Filhol, *Ann. Sci. Géol.* 1876.

[2] E. Van den Broeck, 'Materiaux pour l'étude de l'Oligocene Belge,' *Bull. Soc. Belg. Géol.* 1894.

Lower.
- Sands of Berg with *Pectunculus obovatus*, famous for their large marine mollusks and fish remains, many of which are the same as found in the Clay of Boom.
- Green glaises interstratified with white quartzose sand.
- White quartzose pebble-gravel and black flints.

Tongrian.

Upper or Fluvio-marine.
- Sands and marls of Vieux-Joncs, with some 50 species of fossils, in *Potamides plicatus*, *Cerithium cancellinum*, *Bithinia* *Corbulomya triangula*.
- Glaises of Hénis with *Meretrix incrassata*, *Neritina Duchasteli*, *Faujasi*, *Corbula pisum*, *Pecten Honinghausi*, *Mya angustata*, *depressus*.
- Sands and marls of Bautersem with *Corbicula semistriata*, *Mela cata*, *M. costata*, *Bithinia tenuiplicata*, *B. helicella*.

Lower or Marine.
- Green glaise, glauconitic sand of Neerepen.
- Fine argillaceous and micaceous sand well developed in (Grimmertingen), specially characterised by *Ostrea ventilabrum*. deposit has yielded 231 species of mollusks.[1]
- Fine sand slightly glauconitic.
- Grey plastic clay.
- Coarse gravel of primary and secondary rocks.

Germany.[2]—In northern Germany, while true Eocene deposits are Oligocene groups are well developed both in their marine and fresh-water was from their characters in that region that Beyrich proposed for them Oligocene. They occupy large more or less detached areas or basins, lithological and palæontological variations, but the following general subdivi been established:—

Upper.
- Marine marls, clays, sands, sparingly distributed (Doberg, Hanover; Wilh höhe; Mecklenburg-Schwerin), with *Spatangus Hoffmanni*, *Ter grandis*, *Pecten Janus*, *P. decussatus*, *Arca Speyeri*, *Nassa* *Pleurotoma subdenticulata*.
- Brown-coal deposits of the Lower Rhine,[3] &c., with a flora of less Indian and Australian type, and more allied to that of subtropical America (*Acer*, *Cinnamomum*, *Cupressinoxylon*, *Juglans*, *Nyssa*, *Quercus*, &c.). Some marine beds in this division contain *Ter grandis*, *Pecten Janus*, *P. Münsteri*, &c.

Middle.
- Stettin (Magdeburg) sand and Septaria-clay (*Septarienthon*), with an marine fauna (foraminifera, *Pecten permistus*, *Nuculana deshayesiana*, *Chasteli*, *Astarte Kickxii*, *Cardium cingulatum*, *Pleurotoma scabra*, *obtusus*, *Fusus Koninckii*, *F. multisulcatus*, &c., *Aporrhais speciosa*, *lium Kickxii*). These beds are widely distributed in North Germany, are usually the only representatives there of the Middle Oligocene In Saxony and elsewhere they contain phosphatic deposits, the of lime being often in rounded or elliptical concretions, each of encloses a shell or fishbone. In the Leipzig district *Pectunculus Phil* the most frequent enclosure.[4] In some places a local brown-coal occurs (*Alnus Kefersteini*, *Cinnamomum polymorphum*, *Populus Zadd* *Taxodium dubium*).

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[1] For the list of these shells see G. Vincent, *Ann. Soc. Malacol. Belg.* *Mém.* p. 3.

[2] Beyrich, *Monatsbericht. Akad. Berlin*, 1854, p. 640; 1858, p. 51. A. *Z. D. G. G.* xix. (1867), p. 23. *Abhand. Geol. Specialkart. Preuss.* 1889-94.

[3] C. F. Zincken, 'Physiographie der Braunkohle,' Hannover, 1867, 1872. Dechen, 'Die nutzbaren Mineralien, &c., im Deutschen Reiche,' 1873. For account of the brown-coal of Germany see M. Vollert, 'Der Braunkohlenbergbau,' 1889, the "Festschrift" of the fourth Deutsche Bergmannstage in 1889.

[4] H. Credner, *Abhandl. K. Sächs. Ges. Wissen. Math. Phys. Class.* xxii. 1895.

Lower.

Egeln marine beds (*Ostrea ventilabrum*, *Pecten bellicostatus*, *Nuculana peroralis*, *Arca appendiculata*, *Cardita Dunkeri*, *Cardium Hausmanni*, *Meretrix Solandri*, *Cerithium lævum*, *Pleurotoma Beyrichi*, *P. subconoidea*, *Lyria decora*, *Buccinum bullatum*, &c., and corals of the genera *Turbinolia*, *Balanophyllia*, *Caryophyllia*, *Cyathina*).[1]

Amber beds of Königsberg, consisting of lignitiferous sands resting on marine glauconitic sands, near the base of which lies a band containing abundant pieces of amber. The latter, derived from several species of conifers, especially *Pinus succinifera*, have yielded a plentiful series, estimated at about 2000 species, of insects, arachnids, and myriapods, together with the fruits, flowers, seeds, and leaves of a large number of conifers (*Pinites*, *Pinus*, *Abies*, *Sequoia Langsdorfii*, *Widdringtonites*, *Libocedrus*, *Thuja*, *Cupressus*, *Taxodium*) and dicotyledons (*Quercus*, *Castanea*, *Fagus*, *Myrica*, *Polygonum*, *Cinnamomum*, *Geranium*, *Linum*, *Acer*, *Ilex*, *Rhamnus*, *Deutzia*), together with *Andromeda*, &c.[2] The sands contain Lower Oligocene marine mollusca, sea-urchins, &c.

Lower Brown-coal series—sands, sandstones, conglomerates, and clays with interstratified varieties of brown-coal (pitch-coal, earthy lignite, paper-coal, wax-coal, &c.), a single mass of which sometimes attains a thickness of 100 feet or more. These strata may be traced intermittently over a wide area of northern Germany. The flora of the brown-coal is largely composed of conifers *Taxites*, *Taxoxylon*, *Cupressinoxylon*, *Sequoia*, &c.), but also with *Quercus*, *Laurus*, *Cinnamomum*, *Magnolia*, *Dryandroides*, *Ficus*, *Sassafras*, *Alnus*, *Acer*, *Juglans*, *Betula*, and palms (*Sabal*, *Flabellaria*). The general aspect of this flora most resembles that of the southern states of North America, but with relations to earlier tropical floras having Indian and Australian affinities.

In the Mainz basin some marine sands, clays, and marls in the lower part of its Tertiary deposits are referred to the Oligocene series, and are arranged as follows:—

Cerithium Beds.—Sandy and calcareous strata with brackish-water and land shells (*Potamides plicatus*, *Mytilus Faujasi*, *Helix*, &c.).

Cyrena marl and sand (*Corbicula* (*Cyrena*) *semistriata*, *Potamides plicatus*, *Cerithium margaritaceum*, *Perna Sandbergeri*, &c.).

Septaria-clay with *Nuculana deshayesiana*.

Marine sand of Weinheim with *Ostrea callifera*, *Pectunculus obovatus*, *Meretrix incrassata*, *Natica crassatina*.

Switzerland.[3]—Nowhere in Europe do Oligocene strata play so important a part in the scenery of the land, or present on the whole so interesting and full a picture of the state of the continent when they were deposited, as in Switzerland. In the northern part of the country the marine sands and clays of Mainz and Alsace are found around Bâle, where they reach a thickness of nearly 1000 feet and pass up into fluvio-marine deposits, as shown in the subjoined table:—

Upper Oligocene.	Cyrena Marl (Letten) with *Ostrea cyathula*, fresh-water limestone (*Limnæa*, *Hydrobia*, *Dreissensia*, *Chara*, sands and sandstones (*Potamides plicatus*, *Corbicula* (*Cyrena*), *Cinnamomum*, *Myrica*, &c.) 20 metres.
Middle Oligocene.	Septaria Clay (200 metres) with *Textularia*, *Truncatulina*, *Rotalia*, *Sabal*, *Quercus*, *Eucalyptus*, *Cassia*, &c. Marine sand (100 metres) with *Potamides* (*Tympanotopus*) *trochlearis*, *Ampullina crassatina*, *Pectunculus obovatus*, *Ostrea callifera*, *Pecten*, *Pholas*, *Lamna*, *Halitherium*, *Quercus*, *Cinnamomum*, *Daphnogene*.

[1] For detailed descriptions of the Lower Oligocene molluscan fauna of North Germany see Professor A. von Koenen's elaborate monograph, *Abhand. Geol. Specialkart. Preuss.* x. (1889-92).

[2] 'Flora des Bernsteins,' vol. i. on the coniferæ, H. R. Goeppert, 1883; vol. ii. on the dicotyledons, Goeppert, A. Menge, and H. Conwentz, 1886; 'Monograph. Baltischen Bernsteinbäume,' Danzig, 1890.

[3] Studer's 'Geologie der Schweiz,' vol. ii.; Heer's 'Urwelt der Schweiz,' 1865 (an English translation of which by W. S. Dallas appeared in 1876); 'Flora Fossilis Helvetiæ,' 1854-59; A. Favre, 'Description Géologique du Canton de Genève,' 1880, vol. i. p. 69. Livret Guide dans le Jura et les Alpes de la Suisse, *Congrès Géol. Internat.* 1894.

Farther south the Oligocene formations rise into mountainous ground where their highest member forms the base of the large mass of Nagelfluh (Miocene) of the Rigi and Rossberg. While they include proofs of the presence of the sea, they have preserved a large number of the plants which clothed the Alps, and of the insects which flitted through the woodlands. They form part of a great series of deposits which, termed "Molasse" by the Swiss geologists, were formerly considered to be entirely Miocene. Their lower portions, however, are now placed on the same parallel with the Oligocene beds of the regions lying to the north, and consist of the following subdivisions:—

Red Molasse or Aquitanian Stage (1300 feet in Rigi district): sandstones, grey and red sandy marls with marine bands containing *Cardium lucernense*, *C. Kaufmanni* and brackish or fresh-water bands enclosing *Ziziphus*, *Cinnamomum*, *Smilax*, *Sequoia*.

Tongrian Stage or Upper Flysch (2600 feet in the Reussthal): sandy micaceous shales and sandstones and diabase-sandstone. Characteristic fossils are some of the fishes which are common also in the Oligocene shales of the Carpathians, Croatia, Glarus, and Alsace, such as the herring-like *Meletta*, also *Lepidopus* and *Palæorhynchus*.

Rigi-beds, Ligurian Stage, or Lower Flysch (2600 feet in the Reussthal): grey marly shales, thin-bedded limestones, sandstones, and conglomerates,—*Nummulites*, *Orbitoides*, *Prenaster*, *Terebratulina*, *Spondylus*, *Pecten*, *Lithothamnium*, *Chondrites*, &c.[1]

The upper or lacustrine portion of this series must have been formed in a large lake, the area of which probably underwent gradual subsidence during the period of deposition, until in Miocene times the sea once more overflowed the area. We may form some idea of the importance of the lake from the enormous thickness of the deposits formed in it (*postea*, p. 1270). Thanks to the untiring labours of Professor Heer, we know more of the vegetation of the mountains round that lake, during Oligocene and Miocene time, than we do of that of any other ancient geological period. The woods were marked by the predominance of an arborescent subtropical vegetation, among which evergreen forms were conspicuous, the whole having a decidedly American aspect. Among the plants were palms of American type, the Californian coniferous genus *Sequoia*, alders, birches, figs, laurels, cinnamon-trees, evergreen oaks, with many other kinds.

The portion of the great Flysch formation of the Alps referred to the Oligocene series consists especially of sandstones and dark shales, of which one of the most noted members is the band of shales of Glarus so long known for its abundant fish-fauna. The species (29 in number) obtained from it, many of which are also found in corresponding strata in other parts of Europe, include herrings (*Meletta*), toothed carps (*Prolebias*), cod (*Nemopteryx*), mackerels (*Lepidopus, Palimphyes, Isurichthys, Opisthomyzon*) and other forms.[2]

Portugal.—In the western part of this country, especially in the Lisbon district, and less continuously northwards to Leiria, the Cretaceous formations have been overspread by a plateau of basalt and basalt-tuff, which, between Pruzeres and Rabicha, is 200 metres thick. The age of this volcanic intercalation has not been definitely fixed; it must be post-Cretaceous and may be Eocene or Oligocene. The basalt, as in Ireland, has protected the upper Cretaceous formations from denudation, and has itself been much reduced to detached masses by the progress of waste. The occurrence of this volcanic platform on the western margin of Europe is of much interest in connection with the volcanic history of the continent. The eruptions may possibly have been coeval with the great outpouring of basalt in the north-west, from Ireland and the Hebrides northwards by the Faroes into Iceland.

[1] Livret Guide, p. 143, as above cited.

[2] The fishes of Glarus are described by A. Wettstein in *Abh. Schweiz. Palæont. Ges.* xiii. (1886).

The deposits which overlie the basalt are most completely developed around Lisbon. They consist in the lower part of massive conglomerates, which are regarded as probably of Oligocene age, as they are overlain and sometimes overlapped by marine strata referable to the oldest part of the Miocene series. The materials of these conglomerates include fragments of the Palæozoic and older rocks, together with debris from the Jurassic and Cretaceous formations. Traced northwards between the plain of the Tagus and the serras that lie to the west, the conglomerates are found to be associated with fresh-water limestones.[1]

Vienna Basin.[2]—This area contains a typical series of Tertiary deposits, sometimes classed together as "Neogene." At the bottom lies an inconstant group of marls and sandstones (Aquitanian stage), containing occasional seams of brown-coal and fresh-water beds, but with intercalations of marine strata. The marine layers contain *Potamides plicatus*, *Cerithium margaritaceum*, &c. The brackish and fresh-water bands yield *Melania Escheri* and *Cyrena lignitaria*. Among the vertebrates are *Mastodon angustidens*, *M. tapiroides*, *Rhinoceros sansaniensis*, *Amphicyon intermedius*, *Anchitherium aurelianense*, and numerous turtles. These strata have suffered from the upheaval of the Alps, and may be seen sometimes standing on end. It is interesting also to observe that the subterranean movements east of the Alps culminated in the outpouring of enormous sheets of trachyte, andesite, propylite, and basalt in Hungary and along the flanks of the Carpathian chain into Transylvania. The volcanic action appears to have begun during the Aquitanian stage, but continued into later time. Further curious changes in physical geography are revealed by the other "Neogene" deposits of south-eastern Europe. Thus in Croatia, the Miocene marls, with their abundant land-plants, insects, &c., contain two beds of sulphur (the upper 4 to 16 inches thick, the under 10 to 15 inches), which have been worked at Radoboj. At Hrastreigg, Buchberg, and elsewhere, coal is worked in the Aquitanian stage in a bed sometimes 65 feet thick. In Transylvania, and along the base of the Carpathian Mountains, extensive masses of rock-salt and gypsum are interstratified in the "Neogene" formations.

Italy.—In the north of Italy strata assigned to the Oligocene series are developed to the almost incredible estimated thickness of nearly 12,000 feet. They dovetail regularly with the Eocene below and the Miocene above, and are thus grouped by Professor Sacco in the central part of the northern Apennines:—

Aquitanian Stage. 1000 metres	A great thickness of grey and yellowish sands and occasional greyish marls, the marly character increasing northwards and eastwards. In this stage are included the lignites of Cadibona, also the marls of Chiavòn, Vicentino, from which a large assemblage of fossils has been obtained, particularly remarkable for the number of Chondropterygean and Teleostean fishes, of which some 60 species have been described.
Stampian Stage. 600 metres.	Grey marls more or less sandy and friable.
Tongrian Stage. 2000 metres.	A vast series of sandy marls, sands, conglomerates, and lenticles of lignite, with frequent nummulites (*N. intermedius*, *N. Fichteli*, *N. striata*), *Orbitoides*, fresh-water, brackish, and marine shells[3] (*Ampullina crassatina*, *Potamides*, *Cyrena convexa*, &c.), *Anthracotherium magnum*, &c. Sometimes with greyish violet marls.

[1] P. Choffat, 'Aperçu de la Géologie du Portugal,' Lisbon, 1900.

[2] Suess, 'Der Boden von Wien,' 1860. Th. Fuchs, 'Erläuterungen zur Geol. Karte der Umgebungen Wiens,' 1873; and papers in *Z. D. G. G.* 1877 (p. 653); *Jahrb. Geol. Reichsanst.* vols. xviii. *et seq.* Von Hauer's 'Geologie.' E. Tietze, *Z. D. G. G.* xxxvi. (1884), pp. 68-121; xxxviii. (1886), pp. 26-138.

[3] On the lamellibranchs of this stage in Liguria, see G. Rovereto, *Att. Soc. Ligustica. Sci. Nat.* Genoa, viii.-ix. (1897-98).

Sestian Stage. 20 metres. { A thin band of sandy marls with *Nummulites Fichteli*, *N. rascus*, *N. Boucheri*, *Orbitoides*, *Heterostegina*, &c.

Faroe Islands, Iceland.—The older Tertiary basalt-plateaux, so well displayed in the north-west of Britain, are repeated in the Faroe Islands and in Iceland, where, as in Ireland and Scotland, they comprise intercalated shales and lignites (p. 345). In the island of Suderö (Faroes) the lignite is well developed, and has been worked between the great sheets of basalt. On the east side of the island the following upward succession of deposits may be seen :—(1) upper surface of a basalt lava ; (2) pale clays and dark shales, 20 feet ; (3) pale clays with plant remains, 3 feet ; (4) coal, here only six inches thick, but increasing inland ; (5) volcanic mudstone, 12 feet ; (6) green granular basalt-tuff and mudstone, 3 feet ; (7) Volcanic mudstone with concretions and pieces of fossil wood ; (8) amygdaloidal basalt-lava.[1] In north-western Iceland similar seams of coal or lignite interstratified among the Tertiary basalts have long been known as "Surtarbrand." A number of distinct horizons of these land surfaces have been observed and sometimes, as at Tröllatunga, within the same band of intercalated clays and tuffs, several seams of coal succeed each other. Occasionally also tree trunks are found enclosed in the basalt, like that of Gribon in Mull already described (p. 759).[2]

North America.—The Vicksburg beds, referred to on p. 1242, are not overlain conformably by any further deposits of older Tertiary age. The next succeeding deposits referred to the Miocene series rest more or less trangressively on the Eocene formations. There is thus a gap in the series, represented elsewhere by Oligocene strata. On the Pacific slope the Tejon series (p. 1244) is followed in north-western Oregon by strata which are considered to be Oligocene. They contain *Aturia angustata*, *Dolium petrosum*, *Rimella simplex*, *Neverita globosa*, *Nucula truncata*, *Solen parallelus*, *Mya præcisa*, &c.[3] Much more important, however, are the fresh-water formations which cover a vast area in the interior of the continent, overlie the Eocene series, and have been referred to Oligocene time. These deposits, known as the White River series, cover extensive tracts in the north-east of Colorado, in Nebraska, in south and north Dakota, and among the Cypress Hills in the North-west Territories of Canada. They have a thickness of about 800 feet, and are separable into three groups, each characterised by special mammals as under :—

3. Protoceras beds, containing *Steneofiber*, *Protapirus*, *Aceratherium*, *Hyopotamus*, *Elotherium*, *Eporeodon*, *Leptauchania* and (especially prominent) *Protoceras*.
2. Oreodon beds, of which characteristic fossils are some marsupials (*Didelphys*) ; the rodents *Ischyromys*, *Sciurus*, *Gymnoptychus*, *Eumys ;* the creodont *Hyænodon ;* the carnivores *Daphænos* (*Amphicyon*), *Cynodictis*, *Bunælurus*, *Dinictis*, *Hoplophoneus* (*Drepanodon*) the primitive horse *Mesohippus* (*Anchitherium*), also *Colodon*, *Protapirus*, *Hyracodon*, a number of forms of rhinoceros (*Leptaceratherium*, *Aceratherium*), *Agriochœrus*, *Oreodon* (several species) ; the camels *Pöebrotherium* and *Protomeryx*, *Leptomeryx*, *Hypertragulus*, *Hypisodus*, &c.
1. Titanotherium beds, especially distinguished by the presence of the various Titanotherids, but containing also *Leptaceratherium*, *Aceratherium*, *Elotherium*, and *Agriochœrus*.

The lacustrine deposits of Florissant in the South Park of Colorado, above cited (p. 1248), were probably coeval with some of these groups.

Australasia.—In Victoria, where rocks regarded as of Tertiary age cover nearly half of the colony, it is possible that a separation of part of them as Oligocene may yet be made. The older marine series consists principally of blue or grey clays with septarian nodules, rich in fossils, among which gigantic forms of volutes and cowries are

[1] A. G., *Q. J. G. S.* lii. (1896), p. 340 ; also F. Johnstrup, 'Om Kullagene paa Færöerne,' *K. D. Vid. Selskab. Forhandl.* Copenhagen, 1873.

[2] Th. Thoroddsen, *Geol. Fören. Stockholm.* xviii. (1896), p. 114.

[3] J. S. Diller, 17*th Ann. Rep. U.S. G. S.* 1896, p. 24.

conspicuous. Later than these deposits are those referred to under the Miocene section (*postea*, p. 1274).

In New Zealand the Oamaru series of Captain Hutton (p. 1246) is considered by him to be of Oligocene age,[1] and to comprise the oldest Tertiary rocks in the colony. The most prominent member is a polyzoan limestone found in patches all round the island, which it seems to have encircled. It is chiefly made up of fragments of polyzoa and other organisms, and among its fossils (upwards of 80 species) are species of *Waldheimia*, *Terebratula*, *Terebratella*, *Rhynchonella*, *Pecten*, *Lima*, *Limopsis*, *Crassatella*, *Panopæa*, *Mitra*, *Voluta*, *Marginella*, *Cylichna*, likewise remains of zeuglodont whales (*Kekenodon*), true cetaceans (*Squalodon*), huge sharks (*Carcharodon*), rays (*Trygon*, *Myliobatis*) and the Nautilus *Aturia australis*. At the base of the Oamaru series tachylytes and other basic volcanic rocks are interstratified with the marine sediments.

Section iii. Miocene.

§ 1. General Characters.

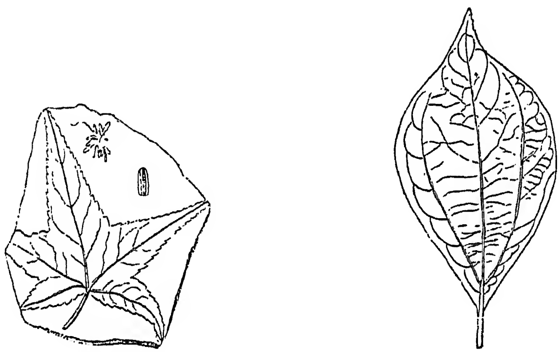
The European Miocene deposits reveal great changes in the geography of the Continent as compared with its condition in earlier Tertiary time. So far as yet known, Britain and northern Europe generally, save an area over the site of Schleswig-Holstein and Friesland, were land during the Miocene period; but a shallow sea extended towards the south-east and south, covering the lowlands of Belgium and the basin of the Loire. The Gulf of Gascony then swept inland over the wide plains of the Garonne, perhaps even connecting the Atlantic with the Mediterranean by a strait running along the northern flank of the Pyrenees. The sea washed the northern base of the now uplifted Alps, sending, as in Oligocene time, a long arm into the valley of the Rhine as far as the site of Mainz, which then probably stood at the upper end, the valley draining southward instead of northward. The gradual conversion of salt into brackish and fresh water at the head of this inlet took place in Miocene time. From the Miocene firth of the Rhine, a sea-strait ran eastwards, between the base of the Alps and the line of the Danube, filling up the broad basin of Vienna, sending thence an arm northwards through Moravia, and spreading far and wide among the islands of south-eastern Europe, over the regions where now the Black Sea and Caspian basins remain as the last relics of this Tertiary extension of the ocean across southern Europe. The Mediterranean also still presented a far larger area than it now possesses, for it covered much of the present lowlands and foot-hills along its northern border, and some of its important islands had not yet appeared or had not acquired their present dimensions.

Among the revolutions of the time not the least important in the geography of the Old World was the continuance and completion of the movements by which the Eocene strata of the great meridional mountain chain had been so convoluted and overthrown. That vast chain, extending from the Alps into Asia, received its final plication and uplift in the

[1] In this series he includes the Ototara and Mawhera series of Hector's "Cretaceo-Tertiary formation," as well as his "Upper Eocene formation," *Q. J. G. S.* xli. pp. 266, 475; *Trans. New Zeal. Inst.* xx. p. 261; xxxii. (1899), p. 169.

Miocene period. One of the results of these terrestrial movements was the restoration and extension of the wide lake or chain of lakes, over the northern or molasse region of Switzerland, in which the red Oligocene molasse had been deposited. The lacustrine deposits accumulated there have preserved with remarkable fulness a record of the terrestrial flora and fauna of the time.

In the New World the physiographical changes were less pronounced. On the Atlantic border the sea margin continued to run not far from the older Tertiary shore-line. The low lands from New Jersey to Florida around the Gulf and up the narrowed Mississippi inlet were submerged, and subsequent elevation has only revealed the mere margin of the deposits then laid down, the main portion being still under water. On the Pacific slope the sea had retreated, owing to an elevation of the Eocene tracts in California, but it eventually once more encroached on



a *b*

Fig. 472.—Miocene Plants.
a, Liquidambar europæum, Braun. ($\frac{2}{3}$); *b*, Cinnamomum Buchi, Heer ($\frac{2}{3}$).

the land and surrounded the long ridge of the Coast Range, depositing fossiliferous sediments which are found far northward into British territory. In the interior the regime of subaerial and lacustrine sedimentation continued, and vast accumulations, partly of volcanic ashes, gathered in a succession of extensive basins. Volcanic eruptions appear to have taken place on a great scale over a large area of the Western States.

The flora of the Miocene period (Figs. 472, 473) indicates a somewhat subtropical climate in the earlier part of the period in Europe, certain of its plants having their nearest modern representatives in India and Australia.[1] Among the more characteristic genera are *Sabal*, *Phœnicites*, *Libocedrus*, *Sequoia*, *Myrica*, *Quercus*, *Ficus*, *Laurus*, *Cinnamomum*, *Daphne*, *Persoonia*, *Banksia*, *Dryandra*, *Cissus*, *Magnolia*, *Acer*, *Ilex*, *Rhamnus*, *Juglans*, *Rhus*, *Myrtus*, *Mimosa*, and *Acacia*. But the climate, if we may judge from the character of the flora, became less warm as the period advanced. As the palms disappeared there came a flora of more

[1] Heer, 'Urwelt der Schweiz'; 'Flora Fossilis Helvetiæ.'

temperate and especially North American type, including an increasing proportion of deciduous trees, and a marked augmentation of the grasses, favourable for the evolution of deer in the North and antelope in the South.[1] Among the more frequent plants of this later time are species of *Glyptostrobus*, *Betula*, *Populus*, *Carpinus*, *Ulmus*, *Persea*, *Ilex*, *Podogonium*, and *Potamogeton*.[2]

The fauna points to somewhat similar climatal conditions in Europe. There occur such molluscan genera as *Ancilla*, *Buccinum*, *Cancellaria*, *Cassis*, *Cerithium*, *Conus*, *Cypræa*, *Mitra*, *Murex*, *Pleurotoma*, *Potamides*, *Pyrula*, *Strombus*, *Terebra*, *Voluta*, *Arca*, *Cardita*, *Cardium*, *Meretrix*, *Congeria*, *Didacna*, *Lima*, *Lucina*, *Mactra*, *Ostrea*, *Panopæa*, *Pecten*, *Pectunculus*, *Spondylus*, *Tapes*, *Tellina*, &c. (Fig. 474). The mammalian forms present

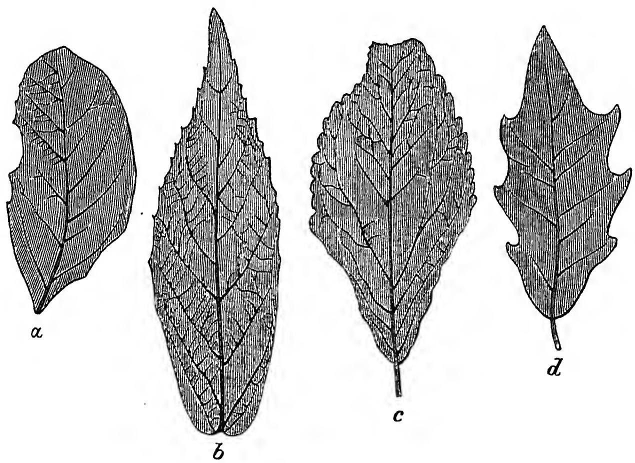


Fig. 473.—Miocene Plants.
a, Magnolia Inglefieldi (½); *b*, Rhus Meriani (nat. size).
c, Ficus decandolleana (½); *d*, Quercus ilicoides (⅔).

many points of contrast with those of the older Tertiary periods. Huge proboscideans now take a foremost place. Among the more important generic types of the fauna are the colossal *Mastodon* (Fig. 475) and *Dinotherium* (Fig. 476), the latter having tusks curving downwards from the lower jaw. With these are associated *Rhinoceros*, of which a hornless and a feebly horned species have been noted; *Anchitherium*, a small horse-like animal, about as big as a sheep, surviving from earlier Tertiary time; *Macrotherium*, a huge ant-eater; *Dicroceros*, a deer allied to the living muntjak of Eastern Asia; *Hyotherium*, an animal nearly related to the hog. A number of living genera likewise made their entry upon the scene, such as the hog, otter, antelope, beaver, and cat. Some of the most formidable animals were the sabre-toothed tigers (*Machærodus*), and

[1] H. F. Osborn, *Ann. New York Acad. Sci.* xiii. (1900), p. 26.
[2] Saporta, 'Monde des Plantes,' p. 272.

the earliest form of bear (*Hyænarctos*). The Miocene forests were also tenanted by apes, of which several genera have been detected. Of these

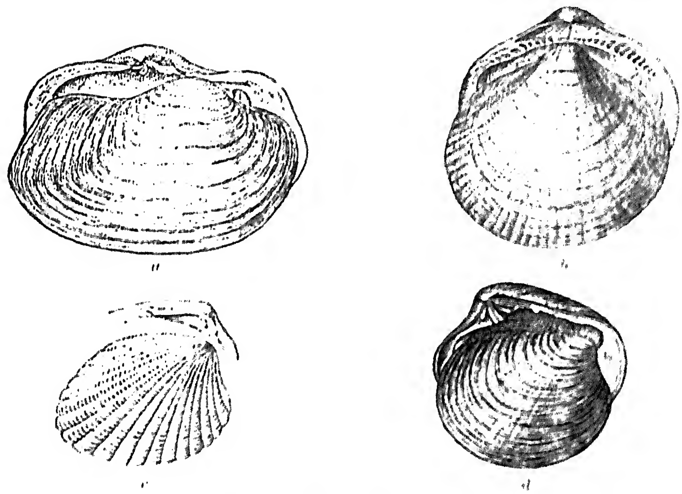


Fig. 474. Miocene Mollusks.

a, Panopaea Faujasii, Men. de la Groye (⅓); *b*, Pectunculus Deshayesi, Mayer (⅓); *c*, Cardita turonica, Ivol. and Peyrot; *d*, Tapes gregaria, Partsch. (½).

Pliopithecus was probably allied to the anthropoid apes; *Dryopithecus* (Fig. 477) was considered by Owen to be allied to the living gibbons, but Gaudry regards it as an anthropoid form, and as the only one yet found fossil

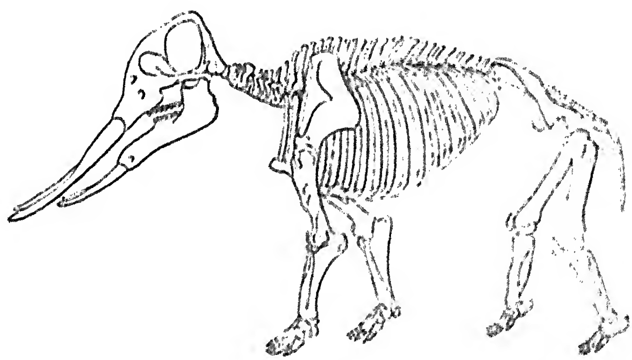


Fig. 475.—Mastodon angustidens, Owen.
Reduced from restoration by M. Gaudry.[1]

which can be compared with man;[2] *Oreopithecus* is supposed to have had affinities with the anthropoid apes, macaques, and baboons.[3]

[1] For a restoration of *M. americanus*, see Marsh, *Amer. Journ. Sci.* xliv. (1892).

[2] *Mem. Soc. Géol. France* (3), i. fasc. 1 (1890).

[3] Gaudry, 'Les Enchainements,' p. 306; Boyd Dawkins, 'Early Man in Britain,' p. 57.

From the Miocene fresh-water deposits of the interior of the United States large additions have been made to our knowledge of the mammals of this period. The Oligocene Titanotheres, Amynodons and Hyracodons had died out before the beginning of Miocene time, and were succeeded by new types. Conspicuous among these were the *Diceratherium* or two-horned rhinoceros, a number of species of

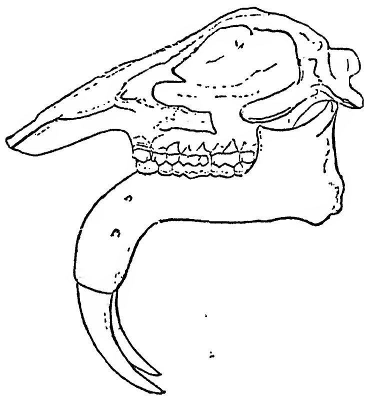


Fig. 476.—Dinotherium giganteum, Kaup., reduced.

the rhinoceros *Aphelops*, the earliest mastodons, and new forms of equidæ (*Protohippus*, *Hipparion*). There were likewise new rodents, edentates, camels, lamas, and deer. The primitive carnivores (creodonts) now died out and gave place to modern forms; the oreodons, hornless rhinoceroses, hyænodons, elotheres, *Hyopotamus*, and *Chalicotherium* likewise became extinct.[1]

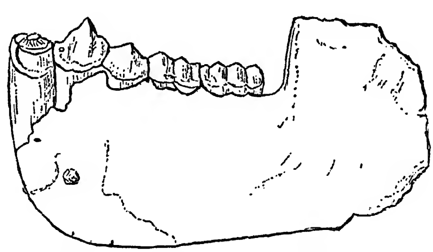


Fig. 477.—Jaw of Dryopithecus Fontani, Gaudry (⅗).

Considerable uncertainty must be admitted to rest upon the correlation of the later Tertiary deposits in different parts of Europe. In many cases, their stratigraphical relations are too obscure to furnish any clue, and their identification has therefore to be made by means of fossil evidence. But this evidence is occasionally contradictory. For example, the remarkable mammalian fauna described by M. Gaudry from Pikermi

[1] H. F. Osborn, "Rise of the Mammalia in North America," *Amer. Assoc.* 1893.

in Attica (*postea*, p. 1294) has so many points of connection with the recognised Miocene fauna of other European localities, that this observer classed it also as Miocene. He has pointed out, however, that in a shell-bearing bed underlying the ossiferous deposit of Pikermi some characteristic Pliocene species of marine mollusca occur. Remembering how deceptive sometimes is the chronological evidence of terrestrial faunas and floras (*ante*, pp. 832, 839, 848), we may here take marine shells as our guide, and place the Pikermi beds in the Pliocene series, a position which is likewise assigned to them, on the ground of their mammalian contents, by a number of able palæontologists.

§ 2. Local Development.

France.—True Miocene deposits are not known to occur in Britain. In France, however, a tolerably full representation of these formations has been preserved. The oldest portion of them consists of sands and gravels which replace the lacustrine accumulations of the Oligocene lakes, and have entombed the remains of many of the mammals of the time. Of later age than these deposits there is found in the district of Touraine, traversed by the rivers Loire, Indre, and Cher, a group of shelly sands and marls, which, as far back as 1833, was selected by Lyell as the type of his Miocene subdivision. These strata occur in widely extended but isolated patches, rarely more than 50 feet thick, and are known as "Faluns," having long been used as a fertilising material for spreading over the soil. They present the characters of littoral and shallow-water marine deposits, consisting sometimes of a kind of coarse breccia of shells, shell-fragments, corals, polyzoa, &c., occasionally mixed with quartz-sand, and now and then passing into a more compact calcareous mass or even into limestone. Along a line that may have been near the coast-line of the period, a few land and fresh-water shells, together with bones of terrestrial mammals, are found, but, with these exceptions, the fauna is throughout marine. This fauna includes abundant corals and numerous mollusks, together with the bones of marine mammalia. Its general character serves to show that the temperature of the sea and no doubt also the land-climate of this region were still considerably warmer than those of the south of France to-day.

In the region of Bordeaux and the plains of the Garonne southward to the base of the Pyrenees, a large area is overspread with Oligocene deposits, equivalents of some of the younger Tertiary series of the Paris basin. Above these fresh-water and marine beds lie patches of faluns like those of Touraine, containing a similar but somewhat older assemblage of marine fossils. Other marine deposits of Miocene age are found running up the valley of the Rhone. But in the south and south-east of France the Miocene strata are mainly of lacustrine origin, sometimes attaining a thickness of 1000 feet, as in the important series of limestones and marls of Sansan and Simorre.

As the result of a comparison of the organic remains obtained from the broad tracts of the marine faluns of Touraine, and of the other districts of France where similar accumulations are found, and from the fresh-water deposits of the western, central, and south-eastern regions of the country, the French Miocene formations have been grouped into the subdivisions shown in descending order in the subjoined table:—

Tortonian (so called from Tortona in North Italy), comprising nodular marls with *Helix turonensis* (molasse of Anjou); in Aquitania a marine molasse with *Ostrea crassissima* and *Pecten solarium*; in Provence sands and sandstones with *Ostrea crassissima*, molasse with *Cardita Jouanneti* (Cabrières, Cucuron) and other deposits, which extend up the valley of the Rhone and have filled up fissures in the Jurassic limestones. Of these fissure-deposits the best known is that of Grive St. Alban, between Lyons and Grenoble, which has yielded 63

species of mammals. The Tortonian stage indicates a general recession of the sea and the spread of lacustrine areas, especially over the region between the valleys of the Rhone and the Danube, these areas being those in which the uppermost Miocene deposits of Switzerland were laid down.

Helvetian (named from its development in Switzerland) is well represented in the Paris basin by the faluns of Touraine above mentioned. These deposits have yielded numerous corals and upwards of 300 species of mollusks, of which the following are characteristic, *Pholas Dujardini*, *Venus clathrata*, *Ostrea crassissima*, *Pecten striatus*, *Cardium turonicum*, *Cardita affinis*, *Trochus incrassatus*, *Cerithium intradentatum*, *Turritella Linnæi*, *T. bicarinata*, *Pleurotoma tuberculosa*, with species of *Cypræa*, *Conus*, *Murex*, *Oliva*, *Ancilla*, and *Fasciolaria*. This assemblage of shells indicates a warmer climate than that of Southern Europe at the present time. The associated mammalian bones include the genera *Mastodon*, *Rhinoceros*, *Hippopotamus*, *Chæropotamus*, deer, &c., and extinct marine forms allied to the morse, sea-cow, and dolphin. Similar faluns, rather later in age, are found in Anjou, Maine, Brittany, and the Cotentin, Farther south in the Armagnac (Aquitania) marine were replaced by lacustrine conditions, and a mass of variegated marls and calcareous sandstones accumulated to a depth of about 1000 feet. These strata (Calcaires de Sansan et de Simorre) have acquired great celebrity from the abundance and variety of their mammalian fauna, which includes *Hyotherium*, antelope, beaver, vole, *Hyænarctos*, *Machærodus*, cat, *Dryopithecus*, &c.

Langhian (from Langhe, Italy) or Burdigalian (from Bordeaux) represented in the Paris basin by the Sables de l'Orléanais, de la Sologne and de l'Eure. These fluviatile accumulations are particularly interesting from the terrestrial fauna preserved in them, which includes *Dinotherium giganteum*, *Mastodon angustidens*, *M. tapiroides*, *M. pyrenaicus*, *Rhinoceros Schleiermacheri*, *R. sansaniensis*, *R. brachypus*, *Anchitherium aurelianense*, *Anthracotherium onoideum*, *Amphicyon giganteus*, *Machærodus cultridens*, *Helladotherium Duvernoyi*, *Dicroceras elegans*, and several apes and monkeys (*Pliopithecus*, *Dryopithecus*). As Professor Gaudry has observed, we have here evidence of the commencement of the reign of proboscideans and apes. In Aquitania the deposits of this stage are marine and consist of faluns typically displayed around Bordeaux. Among their fossils are *Clypeaster marginatus*, *Orbitoides* (*Lycophris*) *lenticularis*, *Cardium burdigalinum*, *Pecten burdigalensis*, *Lucina columbella*, *Oliva plicaria*, with teeth of sharks and bones of dolphins. The sea at this period stretched across Provence, ascended the valley of the Rhone and swept round the west end of the Alps, leaving behind as its record a series of conglomerates and sandy and marly deposits with characteristic shells. These strata have since been folded and faulted in the great movements of upheaval which gave its final form to the Alpine chain.

Belgium.—In this country, the upper Oligocene strata of Germany are absent. In the neighbourhood of Antwerp certain black, grey, or greenish glauconitic sands ("Black Crag," Bolderian, and Anversian) present palæontological characters which were at one time supposed to indicate a mingling of Miocene and Pliocene forms. These deposits were accordingly termed by some geologists Mio-pliocene. They consist of gravelly sands at the base, containing cetacean bones (*Heterocetus*), fish-teeth, *Ostrea navicularis*, *Pecten Caillaudi*, &c. They are followed by sands with *Pectunculus Deshayesi* (*pilosus*), and these by sands with *Panopæa Menardi*. More recent research has shown that the lower part of the series of deposits is Miocene,[1] and is separated by a break and erosion-line from the superincumbent Diestian group, which is referable to the Pliocene series.

Germany.—Certain deposits of dark clay and sand which spread over parts of the north-west of Germany, and contain *Conus Dujardini*, *C. antediluvianus*, *Fusus festivus*, *Isocardia cor*, *Pectunculus Deshayesi* (*pilosus*), *Limopsis aurita*, &c., are referred to the Miocene formations. These are doubtless a prolongation of the Belgian series. Elsewhere the deposits referable to this geological period are lacustrine or fluviatile in origin, and are especially marked by the occurrence in them of brown-coals which are worked.

[1] E. Van den Broeck, *Ann. Soc. Malac. Belg.* xix. (1884).

In the Mainz Tertiary basin an important series of marine, brackish, and fresh-water deposits occurs, which has been arranged by Fridolin Sandberger as follows :[1]—

Pliocene—
 Uppermost brown-coal.
 Bone-sand of Eppelsheim (Dinotherium-sand), see p. 1293.
Miocene—
 Clay, sand, &c., with leaves. Brown-coal of the Wetterau and Vogelsberg.
 Limestone with *Hydrobia acuta*, *Helix moguntina*, *Planorbis*, *Dreissensia*, &c.
 Corbicula beds with *Corbicula Faujasii*, *Hydrobia inflata*, *H. acuta*.
 Cerithium limestone and land-snail limestone.
 Sandstone with leaves (*Cinnamomum*, *Sabal*, *Quercus*, *Ulmus*).
Oligocene (see p. 1257).

The lower Miocene beds of this area present much local variation, some being full of terrestrial plants, some containing fresh-water, and others brackish-water and marine shells, indicating the final shoaling of the Oligocene fjord which ran down the upper valley of the Rhine as far as Mainz. Among the plants are species of *Quercus*, *Ulmus*, *Planera*, *Cinnamomum*, *Myrica*, *Sabal*, &c. The land-snail limestone contains numerous species of *Helix* and *Pupa*, with *Cyclostoma* and *Planorbis*. The *Cerithium* limestone contains marine or estuarine shells, as *Perna*, *Mytilus*, *Cerithium* (*C. Rahtii*, *Potamides plicatus*), *Nerita*. Among the various strata, bones of some of the terrestrial mammals of the time occur (*Cænotherium*, *Palæomeryx*). The Litorinella limestone, the most extensive bed in the series, is composed of limestone, marl, and shale, sometimes made up of *Hydrobia acuta*, in other places of *Dreissensia Brardi*, or *Mytilus Faujasii*. Abundant land and fresh-water shells also occur. Of greater interest are the mammalian remains, which include those of *Dinotherium giganteum*, *Palæomeryx*, *Cænotherium*, *Rhinoceros incisivus*, *Hipparion* (*Hippotherium*) and *Cervus*. The flora of the higher parts of this Miocene series includes several species of oak and beech, also varieties of evergreen oak, magnolia, acacia, styrax, fig, vine, cypress, and palm.

Vienna Basin.[2]—Overlying the Aquitanian stage (p. 1259), where that is present, in other cases resting unconformably upon older Tertiary rocks, come the younger Tertiary or Neogene deposits of the Vienna basin—a large area comprising the vast depression between the foot of the eastern Alps near Vienna, the base of the plateaux of Bohemia and Moravia, and the western slopes of the Carpathians. This tract communicated with the open Miocene sea by various openings in different directions. Its Miocene deposits are composed of two chief divisions or stages as follows, in descending order :—

Sarmatian or Cerithium Stage.—Sandstones passing into sandy limestones and clays, or "Tegel" (the local name for a calcareous clay). The following subdivisions occur around Vienna :—

Upper Sarmatian Tegel, or Muscheltegel—distinguishable from the Hernals Tegel below by an abundance of shells (*Tapes gregaria* (Fig. 474), *Ervilia*, *Cardium*, &c,), 295 feet.

Cerithium-sand—a yellow, abundantly shell-bearing, quartz-sand—the main source of water supply at Vienna, where it is sometimes nearly 600 feet thick. It yields *Cerithium pictum*, *C. rubiginosum*, *C. disjunctum*, *Murex sublavatus*, *Buccinum duplicatum*, *Tapes gregaria*, *Mactra podolica*, *Ervilia podolica*, *Cardium obsoletum*, &c.

Hernals Tegel—sand and gravel, with *Rissoa angulata*, *Cerithium*, *Viviparus*, remains of seals (*Phoca vindobonensis*) turtles, fishes and land plants.

The Sarmatian stage is characterised by the prodigious number of individuals of a comparatively small number (scarcely 50) of species of shells. The

[1] 'Untersuchungen über das Mainzer Tertiärbecken,' 1853 ; 'Die Conchylien des Mainzer Tertiärbeckens,' 1863.

[2] T. Fuchs, *Z. D. G. G.* 1877, p. 653 ; Hörnes and Partsch, 'Die Fossil. Mollusken Tertiär. Beckens,' Wien, 1851-70 ; Ettingshausen, 'Die Tertiärfloren d. Oesterr. Monarchie,' 1851 ; Von Hauer's 'Geologie,' p. 560 ; F. Toula, 'Lehrbuch der Geologie,' 1900, pp. 311-317.

denudatus, *Solenomya Doderleini*) and gasteropods, with some cephalopods, particularly *Aturia Aturi*, and fishes (*Meletta*).

Switzerland.—Immediately succeeding the strata described on p. 1258, as referable to the Oligocene series, come the following groups in descending order:—

Upper fresh-water Molasse and brown-coal (Oeningen or Tortonian stage), consisting of sandstones, marls, and limestones, with a few lignite-seams and fresh-water shells, and including towards the top the remarkable group of plant- and insect-bearing beds of Oeningen.[1]

Upper marine or St. Gall Molasse (Helvetian stage)—sandstones and calcareous conglomerates, with 37 per cent of living species of shells, which are to be found partly in the Mediterranean, and partly in tropical seas: *Pectunculus Deshayesi* (*pilosus*), *Panopæa Menardi*, *Cardita Jouanneti*, *Conus ventricosus*, &c.

Lower fresh-water or Grey Molasse (Lhaugian stage, Mayencian, Burdigalian),—sandstones with abundant remains of terrestrial vegetation, and containing also an intercalated marine band with *Cerithium lignitarium*, *Murex plicatus*, *Venus clathrata*, *Ostrea crassissima*, &c.

The lower Miocene beds (1st Mediterranean stage of Suess) in the Bâle district consist of grey sands and sandstones, at the base about 40 metres thick, and containing land-plants (*Alnus*, *Cinnamomum*). These are surmounted by fresh-water limestones, gypsum, and chert, which attain a thickness of 180 metres, and enclose such shells as *Helix rugulosa*, *Planorbis cornu*, *P. declivis*, and remains of *Chara*. The Grey Molasse of Lausanne has furnished numerous fan-palms, laurels, figs, acacias, and water-lilies. In the Lucerne district an intercalation of marine strata is found in the Lower division, containing a large number of individuals and few species (*Trochus patulus*, *Natica burdigalensis*, *Tapes vetula*, *T. helvetica*, &c.). The massive conglomerates of the Rigi (Kalknagelfluh and variegated or polygenetic Nagelfluh), which with their intercalated marls and beds of sandstone reach a thickness of 1200 to 1800 metres (3900 to 5900 feet), rest upon the red molasse (p. 1258) and are believed to represent the Lower and Middle divisions of the Miocene series, or both the first and second Mediterranean stages of Suess. These enormous accumulations of coarse detritus appear to have been gathered together along the northern front of the Alps, partly from the waste of the older rocks, which can still be seen, but partly also from rocks which do not now appear at the surface. The finer layers of sediment enclose remains of *Sequoia Langsdorfi*, *Zingiberites multinervis*, *Rhamnus Gaudini*, *Cinnamomum Scheuchzeri*, &c.[2]

The St. Gall molasse is regarded as a marine facies of the second Mediterranean Stage or Middle Miocene of Switzerland. In the Rigi district the Upper division of the series is represented by marls and sandstones of lacustrine origin (Knauermolasse) with *Helix*, *Limnæa dilatata*, *Planorbis Mantelli*, *Melania* (*Melanoides*) *Escheri*, *Unio flabellatus*, together with *Salix*, *Quercus*, *Cinnamomum*, &c. But the most noted member of the Upper Miocene of Switzerland is to be recognised in the group of thin bedded fresh-water limestones of Oeningen at the end of the Lake of Constance. From the quarries there, now abandoned, Heer obtained some 50 vertebrates, 826 specimens of insects, some 40 other invertebrates and 475 species of plants. In these strata, so gently have the leaves, flowers, and fruits fallen, and so well have they been preserved, we may actually trace the alternation of the seasons by the succession of different conditions of the plants. Selecting those plants which admit of comparison, Heer remarks that 131 might be referred to a temperate, 266 to a sub-tropical, and 85 to a tropical zone. American types are most frequent among them; European types stand next in number, followed in order of abundance by Asiatic, African, and Australian. Judging from the proportion of species, the total insect fauna may be presumed to have been then richer in some respects than it now is in any part of Europe. The wood-beetles were specially numerous and large. Nor did the large animals of the land

[1] Heer, 'Urwelt der Schweiz,' p. 453.

[2] Livret Guide, *Congrès Geol. Internat*, 1894.

escape preservation in the silt of the lake. We know, from bones found in the Molasse, that among the inhabitants of that land were species of tapir, mastodon, rhinoceros, and deer. The woods were haunted by musk-deer, apes, opossums, three-toed horses, and some of the strange, long-extinct Tertiary ruminants, akin to those of Eocene times. There were also frogs, toads, lizards, snakes, squirrels, hares, beavers, and a number of small carnivores. On the lake, the huge *Dinotherium* floated, mooring himself perhaps to its banks by the two strong tusks in his under jaw. The waters were likewise tenanted by numerous fishes, of which 32 species have been described (all save one referable to existing genera), crocodiles, and chelonians.

Italy.—The enormous Aquitanian stage of Liguria (p. 1259) is followed by (1) blue homogeneous marine marls (of Langhe, whence the term Langhian), reaching a depth of nearly 2000 feet and marked by the abundance of pteropods, also *Ostrea neglecta*, *Cassidaria vulgaris* and *Aturia aturi*. This Langhian or Burdigalian stage is surmounted by (2) the Helvetian stage (3280 feet), composed of three divisions: a lower (1000 to 1300 feet) composed of shaly marls rich in *Vaginella*, *Cleodora*, &c.; a middle (700 to 750 feet) consisting of yellowish sandy molasse with bryozoa, *Pecten ventilabrum*, *Terebratula miocenica*, &c.; and an upper (more than 300 feet) composed of beds of conglomerate and nullipores, with oysters, pectens, &c. This stage is well developed on the hill of the Superga near Turin, where the lowest member is a conglomerate[1] 1000 or 1300 feet thick, containing pebbles of serpentine and numerous fossils (*Cardita Jouanneti*, *Ancilla glandiformis*, and other falun species) and overlain by some 650 feet of sandy molasse (*Pecten ventilabrum*, *Cidaris avenionensis*), which is followed by a conglomerate with nullipores. (3) The Tortonian stage, which supervenes on these strata, consists of about 650 feet of blue marls, forming a remarkably persistent band, and noted for the profusion of its organic remains, especially of *Pleurotomaria*, together with *Conus antiquus* and other species, *Trochus patulus*, *Turritella triplicata*, *Voluta rarispina*, *Ancilla glandiformis*, &c.[2]

Greenland.[3]—One of the most remarkable geological discoveries of modern times has been that of Tertiary plant-beds in North Greenland. Heer has described a flora extending at least up to 70° N. lat., containing 137 species, of which 46 are found also in the Central European Miocene basins. More than half of the plants are trees, including 30 species of conifers (*Sequoia*, *Thujopsis*, *Salisburia*, &c.), besides beeches, oaks, planes, poplars, maples, walnuts, limes, magnolias, and many more. These plants grew on the spot, for their fruits in various stages of growth have been obtained from the deposits. From Spitzbergen (78° 56′ N. lat.) 136 species of fossil plants were named by Heer. But the last Arctic expedition of the British Navy brought to light a bed of coal, black and lustrous like one of the Palæozoic fuels, from 81° 45′ N. lat. It is from 25 to 30 feet thick, and is covered with black shales and sandstones full of land-plants. Among these, Heer noticed 30 species, 12 of which had already been found in the Arctic Miocene zone. As in Spitzbergen, the conifers are most numerous (pines, firs, spruces, and cypresses), but there occur also the Arctic poplar, two species of birch, two of hazel,

[1] On the origin of the Miocene conglomerates of the Ligurian Apennines, see L. Mazzuoli, *Boll. Com. Geol. Ital.* 1888. This author, rejecting the glacial origin which Gastaldi and other writers have claimed for these enormous masses of coarse detritus, sometimes more than 1300 feet thick, regards them as littoral deposits formed during the depression of the region at the end of the post-Eocene uplift. One of the most valuable papers on the Italian Miocene and Pliocene is by C. De Stefani, "Terrains Tertiaires Supérieurs du Bassin de la Mediterranée," *Ann. Soc. Géol. Belg.* xix. (1891), pp. 201-419.

[2] C. Mayer, *B. S. G. F.* (3) v. p. 288; F. Sacco, 'Il Bacino Terziario del Piemonte,' Turin, 1889. Miocene strata have been involved in the last Apennine plication.

[3] Heer, 'Flora Fossilis Arctica,' in seven vols. 1868-83; *Q. J. G. S.* 1878, p. 66. Nordenskjöld, *Geol. Mag.* iii. (1876), p. 207. In this paper sections, with lists of the plants found in Spitzbergen, are given.

an elm, and a viburnum. In addition to these terrestrial trees and shrubs, the lacustrine waters of the time bore water-lilies, while their banks were clothed with reeds and sedges. When we remember that this vegetation grew luxuriantly within 8° 15′ of the North Pole, in a region which is now in darkness for half of the year, and almost continuously buried under snow and ice, we can realise the difficulty of the problem in the distribution of climate which these facts present to the geologist.

India.—The Oligocene and Miocene deposits of Europe have not been satisfactorily traced in Asia. As already stated, the upper part of the massive Nari group of Sind may represent some part of these strata. The Nari group is succeeded in the same region by the Gaj group, 1000 to 1500 feet thick, chiefly composed of marine sands, shales, clays with gypsum, sandstones, and highly fossiliferous bands of limestone. The commonest fossils are *Ostrea multicostata*, and the urchin *Breynia carinata*. Some of the species are still living, and the whole aspect of the fauna shows it to be later than Eocene time. The uppermost beds are clays with gypsum, containing estuarine shells and forming a passage into the important Manchhar strata. The Manchhar group of Sind consists of clays, sandstones, and conglomerates, computed to be sometimes 10,000 feet thick, divisible into two sections, of which the lower may possibly be Miocene, while the upper may represent the Pliocene Siwalik beds (p. 1297). As a whole, this massive group of strata is singularly unfossiliferous, the only organisms of any importance yet found in it being mammalian bones, of which 22 or more species have been recognised. All of these occur in the lower section of the group. They include the carnivore *Amphicyon palæindicus*, three species of *Mastodon*, one of *Dinotherium*, two of *Rhinoceros*, also one of *Sus*, *Chalicotherium*, *Anthracotherium*, *Hyopotamus*, *Hyotherium*, *Dorcatherium* (two), *Manis*, a crocodile, a chelonian, and an ophidian.[1]

North America.—Overlying the Eocene formations (p. 1241), and following in a general way their trend, but sometimes with a slight unconformability, a belt of marine deposits, referred to the Miocene period, runs along the Atlantic border through the states of New Jersey, Delaware, Maryland, Virginia, North and South Carolina, and Georgia. These strata are grouped as shown in the subjoined table:—

3. Yorktown or Chesapeake beds, well developed at Yorktown, Virginia, in Maryland, along the rivers and on the west shore of Chesapeake Bay. Among the characteristic fossils are *Ostrea percrassa*, *Pecten jeffersonius*, *Arca idonea*, *Pectunculus subovatus*, *Astarte undulata*, *Crassatella undulata*, *Lucina anodonta*, *Venus cortinarea*, *Meretrix marylandica*, *Dosinia acetabula*, *Panopæa reflexa*, *Corbula idonea*, *Tellina biplicata*, *Typhis acuticosta*, *Fusus exilis*, &c.
2. Chipola beds, so named from their development along the River Chipola in Florida, their most fossiliferous portion being ferruginous sands which have yielded nearly 400 species. The gasteropods are specially prominent (*Strombus Aldrichi*, *Turritella indenta*, *T. subgrundifera*, *T. chipolana*, *Bittium chipolanum*).
1. Chattahoochee beds, well displayed on Chattahoochee River in south-west Georgia and north-west Florida. The fauna, which resembles that of the Miocene deposits of the West Indian islands and Central America, includes the species named by Heilprin *Orthaulax pugnax*, *Pyrazisinus campanulatus*, *P. acutus*, *Cerithium hillsboroense*, *Vasum subcapitellum*, *Turritella Tampæ*, and others.

Along the Pacific Coast representatives of the marine Miocene formations are likewise found in California and northwards in Washington, Oregon, British Columbia, and Alaska. In California the so-called Ione formation, consisting of clays, sands, and sandstones about 1000 feet thick, is referred to the Miocene series. In the Sacramento valley it is surmounted by a group of volcanic tuffs called the Tuscan formation. In the Mount Diablo region the Miocene series consists of coarse grey sandstones with *Ostrea titan*. In Oregon the strata known as the Astoria shales and sandstones have a wide distribution on both sides of the Coast Range. They contain *Yoldia impressa*,

[1] Medlicott and Blanford's 'Geology of India,' p. 310.

Y. Cooperi, Nucula divaricata, N. truncata, Mactra albaria, &c.[1] The Astoria group of marine fossils is well developed in Alaska.[2]

As in the earlier periods of Tertiary time, the Miocene deposits in the interior of the Continent are of fresh-water origin. They are generally believed to have been deposited in a succession of broad lakes, and are regarded as divisible into two groups, the one representing the lower and the other the upper portions of the Miocene series. The lower is well displayed in Eastern Oregon, where it forms the John Day group, largely composed of volcanic tuffs, and reaching a thickness of several thousand feet. The upper division consists of two sub-stages, of which the older is named the Deep River sub-stage (150 feet), from its development on the Deep River, Montana, north of the Yellowstone Park. The younger or Loup Fork (Nebraska) substage, about 400 feet thick, partly of lacustrine and partly of fluviatile origin, has a wide distribution, seeing that its representatives have been traced from Oregon into Mexico.[3]

Among the characteristic mammals of the John Day group are the rodents, *Sciurus Wortmanni, Allomys nitens, A. hippodus, Entoptychus planifrons, Paciculus lockingtonianus, Lepus ennisianus*, the carnivores *Paradaphænus* (*Amphicyon*) *cuspigerus. Nothocyon* (*Galecynus*) *lemur, Temnocyon altigenis, Dinictis cyclops, Archælurus debilis* &c. ; horses (*Mesohippus* or *Anchitherium*), rhinoceroses (*Diceratherium*), the elotherid *Boöchœrus humerosus*, the pig *Bothrolabis*, the oreodonts *Ágriochœrus, Eporeodon, Merycochœrus* (*Oreodon*), and the camels *Protomeryx* and *Hypertragulus*. The Loup Fork beds have yielded a still more varied mammalian fauna, which comprises rodents (*Mylagaulus, Ceratogaulus, Steneofiber*), carnivores (*Ælurodon*, four species, *Amphicyon, Cynarctus, Pseudælurus*), elephants, horses (*Anchippus, Protohippus*, several species, *Pliohippus, Hipparion*), rhinoceroses (*Aceratherium, Teleoceras*, several species), oreodonts (*Merychyus, Cyclopidius*), camels (*Procamelus*, several species, *Protolabis, Miolabis*), deer (*Blastomeryx, Cosoryx*) and bisons.

South America.—In the southern part of this Continent a great series of Tertiary formations represents the Miocene, Pliocene, and Pleistocene periods, but the precise correlation of the different members with those of North America and the Old World has not yet been settled. The Patagonian formation, which covers so vast an area, is of marine origin, and has yielded some 200 species of invertebrates. The general character of these organisms points to their being of Miocene age.[4] A remarkable feature in them and in the vertebrate fauna of the overlying formation is the striking affinities they show to the Miocene and living forms of Australia and New Zealand (Pareora beds), perhaps indicating either a land connection or shallow seas and islands between South America and Australasia. Above the Patagonian comes the Santa Cruz formation, where mammalian remains have been met with in greater abundance than in any other known deposit. Even more remarkable than their numbers are their variety and their contrast to those of the northern continents. The fauna is marked by the presence of numerous carnivorous and herbivorous marsupials, by an extraordinary variety of edentates, sloths, armadillos, and ant-eaters, by many genera of ungulates belonging to peculiar orders (*Typotheria, Litopterna, Toxodontia*), and by South American types of monkeys and rodents. Besides these positive features, the assemblage of organisms is further distinguished by the absence of families of common occurrence elsewhere. There are no

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1 J. S. Diller, *17th Ann. Rep. U.S. G. S.* Part i. (1896), p. 29.

2 For a list of the Alaskan localities and the species found at them, see W. H. Dall and G. D. Harris, *Bull. U.S. G. S.* 84 (1892), p. 253.

3 The upper part of the Loup Fork group, according to Professor Scott, may be Pliocene.

4 A. E. Ortmann has published an account of the Tertiary invertebrates. He regards the Patagonian beds as of Lower Miocene age, dwells on the remarkable affinities of the faunas of South America, New Zealand, and Australia, and discusses the theory of an Antarctica or Antarctic Continent, *Princeton University Reports from Expedition to Patagonia*, vol. iv. Part ii. pp. 303-310.

true carnivores, creodonts, artiodactyls, perissodactyls, elephants, mastodons, or bats.[1] Unconformably above the Santa Cruz formation lie the Cape Fairweather beds, which from their fossils are regarded as Pliocene.[2]

Australasia.—In Victoria certain deposits later in date than those mentioned on p. 1260 have been referred to the Miocene period. They indicate marine, lacustrine, and terrestrial conditions, with the existence of contemporaneous volcanic activity towards the end of the series. The marine rocks consist mainly of calcareous sandy strata and limestones, with *Cellepora*, *Spatangus*, *Terebratula*, &c. The lacustrine deposits are clays and lignites, and the fluviatile materials consist of gravels and sands which are often auriferous. Great sheets of basalt, forming the older volcanic series, have been poured over these various accumulations, which are sometimes 300 feet thick. A large number of plants, mollusks, fishes, and marine mammals has been obtained from this Miocene series.[3]

Rocks assigned to Miocene time in New Zealand have been divided by Hector into: 1st, A lower series, consisting of calcareous and argillaceous strata widely spread over the east and central part of the North Island and both sides of the South Island. They can be traced to a height of 2500 feet above the sea. Marine shells abound in them, including 55 species which are found among the 450 shells that now live in the adjacent seas. Some of the most notable fossils are *Dentalium irregulare*, *Pleurotoma awamoaensis*, *Conus Trailli*, *Turritella gigantea*, *Buccinum Robinsoni*, *Cucullæa alta*. In some places thick deposits of an inferior kind of brown-coal occur in this subdivision. 2nd, An upper series composed of littoral or sub-littoral accumulations of sand, gravel, and clay. They have yielded 120 recent species of shells, and 25 species which appear now to be extinct. Specially characteristic are *Ostrea ingens*, *Murex octagonus*, *Fusus triton*, *Struthiolaria cingulata*, *Chione assimilis*, *Pecten gemmulatus*.[4]

According to the classification of Captain Hutton, the Miocene rocks of New Zealand are comprised in his Pareora series (p. 1246), which, occasionally overlying beds of coal, consists chiefly of soft sandstones and clays, with limestones on the east coast of the North Island from Wellington to Hawke's Bay. It has yielded about 235 species of mollusks, of which 51 are common to the Oamaru series below, and from 20 to 65 per cent are still living. The large size of some of the shells is remarkable, especially those of the genera *Ostrea*, *Pecten*, *Lima*, *Cucullæa*, *Crassatella*, *Cardium*, *Meretrix*, *Dentalium*, *Pleurotomaria*, *Turbo*, *Scalaria*, *Turritella*, and *Natica*. The fauna has thus a somewhat tropical aspect, which is supported by the flora found among the shales and lignites in the upper part of the series. The fruit of palm trees has been met with not only near the northern end of the North Island, but even as far south as Oamaru in the South Island (lat. 45° S.). An interesting feature of this series of strata is the evidence it contains of contemporaneous volcanic activity. It includes remnants of the last eruptions of the South Island and the earliest of those which now began in the North. The latter are shown in the andesites of the Thames gold-fields, Whangarei Heads and Great Barrier Island, and in the trachytes of Hicks Bay, all of which belong to an early part of the Pareora period. Rather later are the rhyolites of the cliffs around Lake Taupo. Since the marine deposits were laid down they have been upraised to a height

[1] This extraordinary fauna has been partly described by Lydekker in the *Palæontologia Argentina*, 1890 and subsequently, no fewer than 20 genera of edentates being given. More recently the expedition referred to in the foregoing note has been sent from Princeton University, and a vast collection has been made of which an account is now in course of publication. When complete the Palæontological part of the Report will consist of three massive quarto volumes, in which the organic remains will be fully illustrated and described.

[2] W. B. Scott, *Brit. Assoc.* 1900.

[3] R. A. F. Murray, 'Geology and Physical Geography of Victoria,' 1887. M'Coy, 'Prodromus of Victorian Palæontology.' The younger volcanic series is Pliocene (p. 1299).

[4] Hector, 'Handbook on New Zealand,' p. 27.

of 3000 feet above the sea in the South Island, and to not less than 4000 feet in Hawke's Bay.[1]

Section iv. Pliocene.

§ 1. General Characters.

The tendency towards local and variable development, which is increasingly observable as we ascend through the series of Tertiary deposits, reaches its culmination in those to which the name of Pliocene has been given. Doubtless one main cause of this aspect of the sedimentation is to be sought in the comparatively trifling geographical changes which have taken place since the Pliocene strata were accumulated. The sea-floor has, for the most part, been only slightly upraised, so as to expose merely the remains of the shallower and more confined waters. The wide-spread oceanic deposits of the period, which may have been as extensive and as thick as those of earlier ages, still lie buried under the sea. Where a more serious amount of uplift has occurred, much thicker representatives of Pliocene sediments have been brought to light. Thus in the basin of the Mediterranean, especially along both sides of the Apennine chain and in Sicily, where the elevation since Pliocene time has been considerable, a thickness of 1500 feet or more of Pliocene sediments has been raised into land. These deposits were accumulated during a slow depression of the sea-bottom, and their growth was brought to an end by the subterranean movements which culminated in the outbreak of Etna, Vesuvius, and the other late Tertiary Italian volcanoes, and in the uprise of the land between the base of the Apennines and the sea on either side of the peninsula. Great volcanic activity continued to manifest itself in other districts, such as Central France. As a whole, the marine Pliocene deposits of Europe, local in extent and variable in character, reveal the beds of shallow seas, the elevation of which into land completed the outlines of the Continent at the close of Tertiary time. Thus these waters covered the south and south-east of England, spreading over Holland, Belgium, and a small part of northern France, but leaving the rest of northern and western Europe as dry land. Here and there, in south-eastern Europe, evidence exists of the gradual isolation of portions of the sea into basins, somewhat like those of the Aralo-Caspian depression, with a brackish or less purely marine fauna. In some portions of these basins, however, as in the Karabhogas Bay of the existing Caspian Sea, such concentration of the water took place as to give rise to extensive accumulations of salt and gypsum. In a few localities, fluviatile and lacustrine deposits of the Pliocene period have been preserved, from which numerous remains of terrestrial vegetation and mammals have been obtained.

The Pliocene flora is transitional between the luxuriant evergreen and sub-tropical vegetation of the Miocene period and that of modern Europe. From the evidence of the deposits in the upper part of the valley of the Arno, above Florence, it is known to have included species of

[1] Captain Hutton, *Trans. New Zeal. Inst.* xxxii. (1899), p. 171.

general character of the fauna is that of a temperate climate, and is strongly contrasted with that of the Mediterranean stage in the absence of the affinities with tropical or sub-tropical forms, and even with those of the present Mediterranean, and on the other hand in some curious analogies with the living fauna of the Black Sea. Corals, echinoderms, bryozoa, foraminifera are absent or very rare, and the suggestion has been made that the change of the earlier Mediterranean fauna into that of the Sarmatian stage points to a gradual diminution of the salinity of the waters of the Vienna basin, as has happened with the existing Black Sea. The terrestrial flora is characterised by some plants that survived from the earlier or Mediterranean stage; but palms are entirely absent, and the American element in the flora is no longer surpassed by the preponderance of Asiatic types.

Mediterranean or Marine Stage.—A group of strata varying greatly from place to place in petrographical characters, with corresponding differences in fossil contents. It has been divided into two sections, in descending order, as follows:—

(2) Second substage, widely spread over the Vienna basin and extending into the Pannonian region, yielding more than 1000 species of fossils and presenting various phases of sedimentation. Among these phases the more important are:—

Leithakalk, a limestone often entirely composed of organisms. In some places it mainly consists of calcareous algæ (Nulliporenkalk, Lithothamnienkalk); elsewhere of reef-building corals (Korallenkalk), while certain soft varieties are largely made up of bryozoa (Bryozoënkalk). The layers of limestone are often separated by bands of tender marls full of foraminifera (*Amphistegina Haueri*, &c.). The limestone is rich in lamellibranchs (*Ostrea digitalina*, *O. crassissima*, *Pecten aduncus*, *Pectunculus Deshayesi* (*pilosus*), *Venus umbonaria*, *V. multilamella*, *Cardita*, *Cardium*, *Spondylus*, &c.), gasteropods (*Ancilla*, *Cerithium*, *Conus*, *Cypræa*, *Strombus*, *Turritella*), with echini (large clypeasters), fish-teeth (*Carcharodon*, *Lamna*, &c.) and bones of mammals. Along the margin of the basin the limestone passes into sandy and conglomeratic deposits (Leitha-conglomerate or schotter) which contain large oysters, *Pectunculus*, *Pecten*, and abundant specimens of *Clypeaster*.

Neudorf Sands—coarse sands with *Ostrea digitalina*, *Panopæa Menardi*, *Anomia*, *Pecten*, *Pinna*, *Cardita*, *Turritella*, *Conus* and numerous fish-teeth.

Pötzleinsdorf Sands—fine yellow sands with *Tellina planata*, *Lucina columbella*, *Venus umbonaria*, *Meretrix*, *Turritella*.

Marl of Gainfahren, and Grinzing—sandy marls with about 300 species, especially of lamellibranchs and gasteropods.

Baden Tegel—a fine blue plastic clay, abundantly fossiliferous. Species of *Pleurotoma* (*P. cataphracta*, *P. notata*, *P. Lamarcki*) are so conspicuous that the deposit is known as the Pleurotomentegel. Other gasteropods are *Dentalium badense*, *Ancilla glandiformis*, *Cassis saburon*, *Fusus longirostris*, *Natica helicina*, *Ringicula buccinea*, *Conus*, *Mitra*, &c. Among the lamellibranchs are *Corbula gibba* and *Pecten cristatus*.

Grund Beds—Highly fossiliferous marine marls which spread into Moravia. They contain a commingling of the forms found in this and the underlying substage, including *Turritella cathedralis*, *T. bicarinata*, *Pyrula rustica*, *Murex aquitanicus*, *Conus ventricosus*, *Ancilla glandiformis*, *Mytilus Haidingeri*, *Ostrea crassissima*, *Pecten aduncus*, *Venus multilamella*. At the base of the second substage lie the lignitiferous beds of Mauer, near Vienna, and other places, containing *Cerithium lignitarum* and *Ostrea crassissima*.

(1) First substage, presenting a number of lithological and palæontological types, which are believed to have been on the whole of contemporaneous origin. Among these the following may be mentioned:—

Molt beds—with *Cerithium margaritaceum*, *C. plicatum*, *Mytilus Haidingeri*, &c.

Sands of Loibersdorf (*Pecten solarium*, *Cardium Kübecki*, *Pectunculus Fichteli*, *Ostrea crassissima*, *O. digitalina*, *Corbula gibba*, *Mytilus Haidingeri*, &c.

Tellina-sand with *Tellina planata*, *Solen vagina*, *Pharus legumen*, *Turritella cathedralis*.

Coarse sands of Eggenburg and sandy bryozoan limestone, with numerous valves of *Pecten* and *Ostrea*, also Bryozoa, Balani, &c.

Schlier—a grey clay, sometimes laminated, sometimes plastic (Marl, Tegel) which has a wide extension in the Vienna basin, from the border of Bavaria eastwards to Wallachia. It is usually highly fossiliferous containing abundant foraminifera, sea-urchins (*Brissopsis ottnangensis*), pteropods, lamellibranchs (*Pecten*

pine, oak, evergreen-oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, buckthorn, hickory, sumach, sarsaparilla, sassafras, cinnamon, glyptostrobus (Fig. 478), taxodium, sequoia, &c.[1] The researches of Count de Saporta have shown that the flora of Meximieux, near Lyons, comprised species of bamboo, liquidambar, rose-laurel, tulip-tree, maple, ilex, glyptostrobus, magnolia, poplar, willow, and other familiar trees (Fig. 479).[2] The forests of that part of Europe during Pliocene time conjoined some of the more striking characters of those of the present Canary Islands, of North America, and of Caucasian and eastern Asia, including Japan. There is evidence, however, that a marked refrigeration of climate was in gradual progress, during which the plants, such as the palms, especially characteristic of warmer latitudes, one

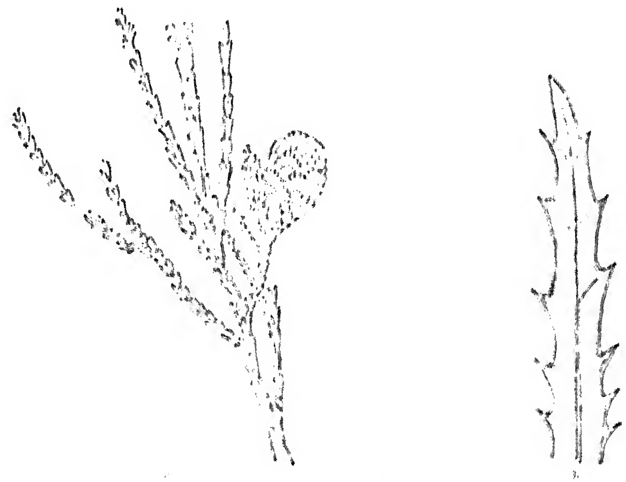

Fig. 479.—Pliocene Plants.
a, Glyptostrobus europæus, Brongn. (½); b, Hakea exalata, Heer.

by one retreated from the European region, or lingered only on its southern borders. In England, towards the end of the Pliocene period, the climate, if we may judge of it from the plants preserved in the Cromer Forest-bed, had come to be very much what it is to-day. Among the vegetable remains found in that deposit are those of many of the familiar forest trees still living in the south-east of England. Some of our common wild flowers and water plants had now made their appearance, such as the buttercup, marsh-marigold, chickweed, milfoil, marestail, dock, sorrel, pondweed, sedge, cotton-grass, reed and royal fern.[3]

[1] Gaudin, 'Feuilles fossiles de la Toscane.' Gaudin and Strozzi, 'Contributions à la Flore fossile italienne.' Lyell, 'Student's Elements,' 4th edit. p. 172.

[2] "Recherches sur les Végétaux fossiles de Meximieux," *Archiv. Mus. Lyon*, i. (1875-76); and his 'Monde des Plantes,' p. 314.

[3] C. Reid, 'Pliocene Deposits of Britain,' *Mem. Geol. Surv.* (1890), pp. 185, 231, and his 'Origin of the British Flora,' 1899.

In the fauna of the Pliocene period, as contained in the various deposits of the time, the invertebrate portion is specially conspicuous. The gasteropods, lamellibranchs, polyzoa, and foraminifera are the more abundant groups. All the gasteropods and lamellibranchs belong to living genera. In the English Pliocene deposits *Aporrhais*, *Buccinum*, *Nassa*, *Natica*, *Neptunea (Chrysodomus)*, *Purpura*, *Rissoa*, *Scala*, *Tritonofusus*,

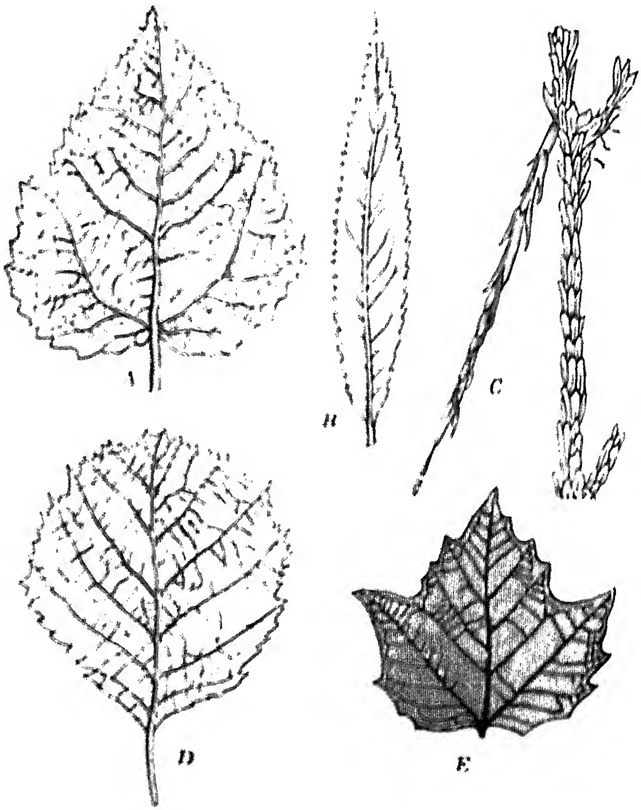

Fig. [illegible].—Pliocene Plants.

(*a*) Populus canescens; (*b*) Salix alba; (*c*) Glyptostrobus europaeus; (*d*) Alnus glutinosa; (*e*) Platanus aceroides.

Trivia, *Trochus (Calliostoma)*, *Turritella* and *Voluta (Aurinia)* are common gasteropod genera. In the same deposits the lamellibranchs are represented by *Astarte*, *Cardita*, *Cardium*, *Cyprina*, *Dosinia*, *Lucina*, *Mactra*, *Nucula*, *Pecten*, *Pectunculus*, *Tellina*, *Venus*, &c. Among the numerous polyzoa more particularly found in the Coralline Crag, are *Eschara*, *Hornera*, *Lepralia*, *Theonoa*, and *Membranipora*. Eleven genera of echinoids

have been obtained in England, the chief being *Echinus*, *Echinocyamus* and *Temnechinus*.[1]

The vertebrate portion of the fauna still retained a number of the now extinct types of earlier time, such as the *Dinotherium* and *Mastodon*. It was specially characterised also by troops of rhinoceroses, hippopotamuses, and elephants, the *Elephas meridionalis* (Fig. 480) being a distinctive form; by large herds of herbivora, including numerous forms of gazelle, antelope, deer, now mostly extinct, and types intermediate between still living genera. Among these were some colossal ruminants, including a species of giraffe and the extinct giraffe-like genera *Helladotherium* (Fig. 487) and *Samotherium*, as well as other types met with among the Siwalik beds of India (*Sivatherium*, Fig. 489, *Bramatherium*). The Equidæ were represented by the existing *Equus*, and by extinct forms, one of the most abundant of which was *Hipparion* (Fig. 481), like a small ass or quagga, with very complex teeth and three toes on each foot, only the central one actually reaching the ground. Besides these animals there lived also various apes (*Mesopithecus*, Fig. 482, *Dolichopithecus*), likewise species of ox, cat, bear, machærodus (Fig. 488), hyæna, fox, viverra, porcupine, beaver, hare, and mouse.

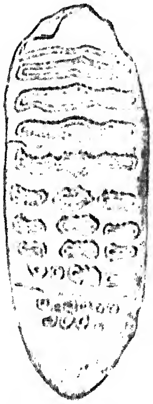

Fig. 480.—Elephas meridionalis, Nesti. Crown of molar (⅓).

The succession of the mammalia during Pliocene time, as worked out by Gaudry, is shown in the subjoined table:[2]

Upper	Arnusian	Stage of Perrier near Issoire, Coupet, Vialette, Haute-Loire, Chagny, Sables of Loire, with a part of the Val d'Arno beds and of the English Crag. Appearance of horses, oxen, elephants, marmots, foxes, bears. Disappearance of apes. The antelopes become rare, the deer increase. The elephant coexists with the Mastodon.
Middle	Astian	Stage of Montpellier and of Casino, Tuscany. Appearance of the semnopithecoid apes. The hipparion still exists, but the *Dinotherium*, *Ancylotherium*, and many other genera of the preceding periods now disappear.
Lower	Messinian	Stage of Pikermi, Baltavar (Hungary), Mont Leberon, Vaucluse, and Concud (Spain). Appearance of the genera *Leptodon*, *Tragoceros*, *Palæoreas*, *Palæotragus*, *Palæoryx*, *Gazella*, *Helladotherium*, deer, *Ancylotherium*, porcupine, *Ictitherium*, hyæna, *Hyænictis*, *Promephitis*. Reign of the herbivora, which form immense herds.

The advent of a colder period is well shown by the change in the aspect of the molluscan fauna as we pass from the older to the younger Pliocene deposits of Europe. On the one hand, a number of northern mollusks make their appearance, while on the other, there is a correspond-

[1] The chief authority on the English Pliocene mollusca is S. V. Wood, "Crag Mollusca," *Palæontograph. Soc.* 1848-82; on the polyzoa, G. Busk, "Crag Polyzoa," *Palæontograph. Soc.* 1859. The Echinodermata have been described by E. Forbes, "Echinodermata of the Tertiaries," *Palæontogr. Soc.* 1852, and by J. W. Gregory, "British Cainozoic Echinoidea," *Proc. Geol. Assoc.* vol. xii. (1891) p. 16. The Foraminifera have been discussed by Jones, Parker, and Brady, "Crag Foraminifera," *Palæontograph. Soc.* 1866 and 1895.

[2] 'Enchaînements du Monde Animal—Mammifères Tertiaires,' p. 5.

ing elimination of southern forms. The proportion of northern species increases rapidly in the next succeeding or Pleistocene series. The Pliocene period, therefore, embraces the long interval between the warm temperate

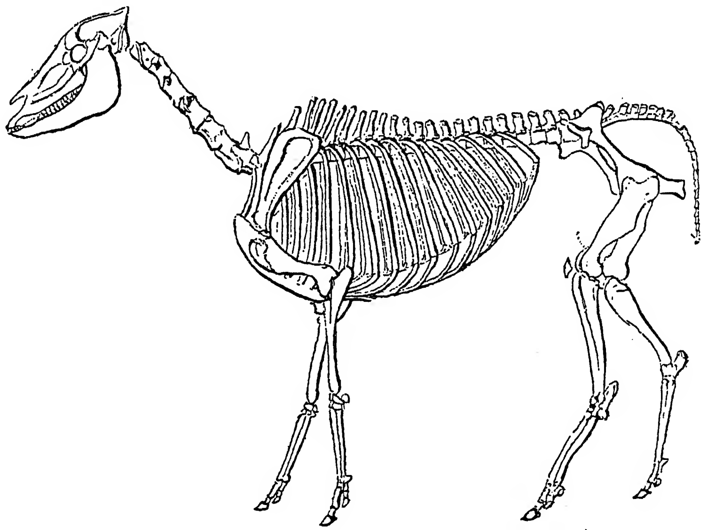

Fig. 481.—Hipparion gracile, Gaudry ($\frac{1}{20}$).

climate of the later ages of Miocene and the cold Pleistocene time. The evidence of change of climate derivable from the English Pliocene marine mollusca may be grouped as in the subjoined table, which shows

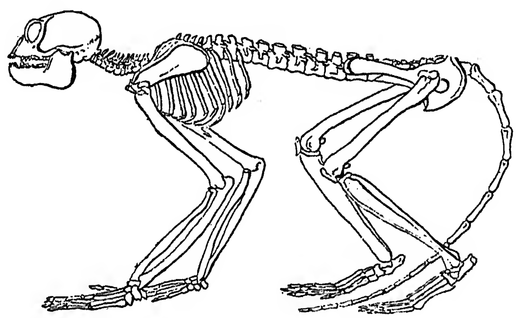

Fig. 482.—Mesopithecus Pentelici, Gaudry ($\frac{1}{8}$).

the gradual extirpation of southern and advent of northern forms in the long interval between the deposition of the oldest and newest Pliocene deposits.[1]

[1] F. W. Harmer, *Q. J. G. S.* lvi. (1900), p. 725 ; see also C. Reid, 'Pliocene Deposits of Britain,' p. 145.

	Not known as living species. Per cent.	Southern forms. Per cent.	Northern forms. Per cent.
Weybourn and Chillesford Crag	11	—	33
Fluvio-marine Crag	11	7	32
Red Crag of Butley	13	13	23
Red Crag of Newbourn	32	16	11
Red Crag of Walton	36	20	5
Coralline Crag	38	26	1

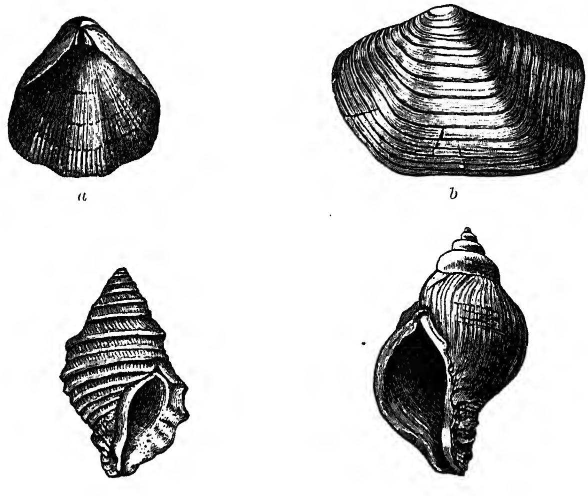

Fig. 483.—Pliocene Marine Shells.
a, Rhynchonella (Hemithyris) psittacea ; *b*, Panopæa norvegica (½); *c*, Purpura lapillus (½) ; *d*, Neptunea (Chrysodomus, Trophon) antiqua (¼). All these species still live in the seas around Britain.

§ 2. Local Development.

Britain.[1]—In the Pliocene period, after a long period of exposure as a land-surface,

[1] Prestwich, *Q. J. G. S.* xxvii. (1871). Lyell, 'Antiquity of Man,' chap. xii. (1863). Searles Wood, "Crag Mollusca," *Palæont. Soc.* (1848-57), and Supplement by S. V. Wood, junr. and F. W. Harmer (1872). H. B. Woodward, "Geology of Norwich," and W. Whitaker, "Geology of Ispwich," &c. both in *Mem. Geol. Survey*. The fullest account of the stratigraphy will be found in the monograph by C. Reid, already cited, on the 'Pliocene Deposits of Britain' (*Mem. Geol. Survey*), which contains a valuable bibliography. The subject has since been discussed in detail by Mr. Harmer (*Q. J. G. S.* liv. (1898), p. 308 ; lvi. (1900), p. 705, also a general summary of his views, *Proc. Geol. Assoc.* xvii. (1902) p. 416). In a new classification of the Pliocene deposits of the east of England, he considers that the upper limit of the older part of the series should be placed immediately above the Lenham beds, and that the Coralline Crag should be made the base of the Newer Pliocene series. He proposes a number of new names for the several members of the whole succession of deposits, derived from the localities where they are best developed, *Q. J. G. S.* lvi. p. 708.

during which a continuous and ultimately stupendous subaerial denudation was in progress, Britain underwent a gentle, but apparently only local, subsidence. We have no evidence of the extent of this depression. All that can be affirmed is that the south-eastern counties of England began to subside, and on the submerged surface some sand-banks and shelly deposits were laid down, very much as similar accumulations now take place on the bottom of the North Sea. These formations, termed generally "Crag," are followed by estuarine and fresh-water strata, the whole being subdivided, according to the proportion of living species of shells, into the following groups in descending order :—

Base of the Pleistocene.	Arctic Fresh-water Bed (with *Salix polaris*, *Betula nana*, &c.).	
Newer Pliocene (cold temperate).	*Yoldia (Leda) myalis* Bed, classed provisionally as Pliocene.	
	Forest-bed group (10 to 60 feet): Upper Fresh-water, Estuarine, Lower Fresh-water.	Gravels with *Elephas meridionalis* at Dewlish.
	Weybourn Crag (and Chillesford Clay ?), 1 to 22 feet.	
	Chillesford Crag (5 to 15 feet).	
	Norwich Crag and *Scrobicularia* Crag (5 to 10 feet).	147 feet at Southwold.
	Red Crag of Butley, &c.	
	Red Crag of Newbourn, Oakley, and Walton.	
Older Pliocene (warm temperate).	St. Erth Beds.	
	Coralline Crag (40 to 60 feet).	
	Lenham Beds (Diestian).	
	Box-stones and phosphate beds (with derivative early Pliocene fossils).	

Older Pliocene.—The deposits of this age probably at one time extended over a large part of the south and south-east of England, but they have been reduced by denudation to a few widely separated patches, the largest of which, around Oxford in Suffolk, does not cover more than about ten square miles. They consist chiefly of shelly sands known as the Coralline Crag of Suffolk, but a small outlier of fossiliferous sand occurs on the edge of the North Downs at Lenham, and other ironstone patches, probably of the same age, cap the Down as far as Folkestone. Far to the west, at St. Erth in Cornwall, an isolated deposit of older Pliocene age has been detected. These thin and scattered fragments convey no adequate conception of the length or importance of the geological period which they represent. As above remarked, it is not until we pass into the north of Italy and the basin of the Mediterranean that we discover the Pliocene period to be represented by thick accumulations of upraised marine strata comparable in extent and thickness to some of the antecedent Tertiary series.

A strongly marked break, both stratigraphical and palæontological, separates the Pliocene deposits of Britain from all older formations. They lie unconformably on everything older than themselves, and in their fossils show a great contrast even to those of the Oligocene series. The sub-tropical plants and animals of older Tertiary time are there replaced by others of more temperate types, though still pointing to a climate rather warmer than that of southern England at the present time.

A conglomeratic deposit (Nodule beds, Box-stones) forms the base of the Red Crag, and sometimes also underlies the Coralline Crag. It includes fragments of various rocks, such as flints, septaria, sandstones, quartz, quartzite, granite, and other igneous materials, together with a miscellaneous assortment of derivative fossils, including Jurassic ammonites and brachiopods, sharks' teeth and other fossils from the London Clay, the teeth of many land mammals (pig, rhinoceros, mastodon, tapir, deer, hipparion, &c.), and pieces of the rib-bones of whales. Many of these organic remains must have been derived from some older Pliocene deposit which has otherwise entirely disappeared. They have been to a large extent phosphatised, and hence have been extracted as a source of phosphate of lime. Among the contents of the deposit some of the most interesting and important are rounded pieces of brown sandstone, known as "box-stones," evidently derived from the denudation of a single horizon, and enclosing

casts of marine shells. The general facies of the assemblage of shells obtained from these fragments points unmistakably to a lost formation, probably of older Pliocene time. At present 16 species have been determined, all of which are well-known British Pliocene forms, except two, which occur in Continental Pliocene deposits.[1]

Lenham Beds, Diestian.—On the edge of the Chalk Down of Kent near Lenham, patches of sand cap the Chalk, and descend into pipes on its surface at a height of more than 600 feet above the sea, and, as above stated, other similar nests of ferruginous sands are met with along the downs as far as Folkestone. At first these deposits were thought to be portions of the base of the Tertiary series, but the occurrence of apparently Pliocene shells in them led to a more thorough investigation of them, with the result that they have been proved to be of the same age as similar deposits which cap the hills on the other side of the Straits of Dover from Boulogne into Belgian Flanders, whence they stretch northwards as a wide continuous sheet into Holland. These sands, known as Diestian, have yielded at Diest and Antwerp a large assemblage of fossils, which prove them to be of older Pliocene age. Of the Diestian fossils of Holland and Belgium so large a proportion has been detected in the Lenham deposits, generally in the form of hollow casts, as to leave no doubt of the geological horizon of these scattered fragments of a formation. About 67 species have been obtained from Lenham, the southern character of which is indicated by the genera *Pyrula*, *Xenophora* (*Phorus*), *Lotorium* (*Triton*), and *Avicula*, with abundant examples of *Arca diluvii*, *Cardium papillosum*, and the polyzoon *Cupularia canariensis*. Some of the extinct species are found elsewhere in Miocene deposits and in the Italian Pliocene formations. The proportion of existing species is reckoned at 57 per cent; 75 per cent of the whole fauna is found in Miocene, and 72 per cent in the Mediterranean Pliocene deposits.[2] It is interesting to notice the great change of level which this fragmentary formation serves to prove since older Pliocene time in the south of England. From the general character of the fauna found at Lenham it is probable that the shells lived in a depth of not less than 40 fathoms of water. This vertical amount, added to the present height of the deposit above the sea, gives a minimum of 860 feet of uplift.[3] At the same time, we cannot but be struck with the evidence which is here presented of great denudation. There may have been a thick accumulation of Pliocene deposits over the south-east of England, but the whole has been swept away, leaving only such portions as escaped by being sheltered in hollows of the Chalk.

Fig. 484.—Pliocene Polyzoon. Theonoa (Fascicularia) aurantium, M. Edw. (½).

St. Erth Beds.—The only other fragments yet known of older Pliocene formations in Britain lie far to the west between St. Ives and Mount's Bay in Cornwall, where a patch of clay at St. Erth, 120 feet above the sea, and probably less than a quarter of a square mile in area, contained in a hollow of the slates, has preserved an interesting series of organic remains. Another outlier occurs on the opposite side of the same valley at the height of 150 feet. Among the forms which connect this deposit with corresponding strata elsewhere the following may be mentioned: *Turbonilla plicatula*, *Columbella sulcata*, *Trivia* (*Cypræa*) *avellana*, *Eulimene terebellata*, *Fissurella costaria*, *Lacuna suboperta*, *Melampus pyramidalis*, *Nassa reticosa*, *Natica millepunctata*, *Ringicula acuta*, *Trochus noduliferens*, *Turritella incrassata*, *Cardita aculeata*, *Cardium papillosum*.[4] The assemblage of fossils indicates a probable depth of water of 40 or

[1] C. Reid, *op. cit.* p. 6 *seq.* F. W. Harmer, *Q. J. G. S.* liv. p. 313; Ray Lankester, *op. cit.* xxvi. 1870. It was possibly from the destruction of the strata overlying the Lenham beds that the Nodule or Box-stone materials were derived.

[2] F. W. Harmer, *op. cit.* p. 312.

[3] C. Reid, *op. cit.* pp. 42, 69.

[4] C. Reid, *op. cit.* pp. 59, 236, *Summary of Progress of Geol. Surv.* for 1901, p. 31.

50 fathoms, and thus points to an elevation of the land to the extent of about 400 feet since Pliocene time.

Coralline Crag (Bryozoan, White, or Suffolk Crag[1]) consists essentially of calcareous sands, containing hardly any inorganic matter, but mainly made up of shells and bryozoa. It is exposed at various localities in the county of Suffolk, between Butler Creek and Aldeburgh. According to the census of Searles Wood, published in 1882, the number of mollusks found in this deposit amounts to 420 species, of which 251 or 60 per cent are still living. The southern character of the fauna is still shown by some of the genera of shells, such as large and showy species of *Voluta* (*Aurinia*), *Cassidaria*, *Cassis*, *Pyrula* (*Ficula*), *Hinnites*, *Chama*, *Cardita*, and *Pholadomya*, likewise *Ovula*, *Mitra*, *Lotorium* (*Triton*), *Vermetus*, *Ringicula*, *Verticordia*, *Coralliophaga*, and *Solecurtus*. Characteristic species are *Cardita corbis*, *C. senilis*, *Limopsis pygmæa*, *Ringicula buccinea*, *Voluta* (*Aurinia*) *Lamberti* (Fig. 486), *Pyrula reticulata*, *Astarte Omalii* (Fig. 485), *Pholadomya histerna*, *Pecten* (*Æquipecten*) *opercularis*, *Lingula Dumortieri*, and *Terebratula grandis*. Hardly less abundant and varied are the bryozoa or "Corallines," from which one of the names of the deposit is taken. No fewer than 118 species have been named, of which 76, or about 64 per cent, appear to be extinct. Specially characteristic and peculiar are the large massive forms known as *Alveolaria* and *Theonoa* (*Fascicularia*) (Fig. 484). There are three species of corals all extinct. Of the 16 species of echinoderms at present known, only three are now living. Remains of fishes are of common occurrence, especially in the form of gadoid otoliths. Teeth and dermal spines of the skate and wolf-fish are met with, and to these shell-eating fish the broken condition of so many of the shells may probably be ascribed. Traces of one of the larger dolphins have been found, but no remains of any of the contemporaneous land-mammals, though a few drifted land-shells show that the land lay probably at no great distance. The Coralline Crag may be regarded as an elevated shell-bank, which accumulated on the floor of a warm sea at a depth of from 25 to 30 or 50 fathoms.[2]

NEWER PLIOCENE.—The British deposits of this age are, so far as we know, confined to the counties of Norfolk and Suffolk. They are separated by a considerable break from the older series, for they lie on an eroded surface of the latter, and pass across it so as to rest upon the Eocene formations, and even on the Chalk. There is likewise a marked contrast between the fauna of the two series. The newer deposits show that the break must represent a long period of geological time, during which a great change of climate took place in Europe, for the southern forms are now found to have generally disappeared, and to have been replaced by northern forms that, following the change of temperature, had migrated from the colder north.

Red Crag.—Under this name is classed a series of local accumulations of dark-red or brown ferruginous shelly sand, which, though well marked off from the Coralline Crag below, is less definitely separable from the Norwich Crag above. Judging from the variations in its fossil contents, geologists have inferred that some portions of the deposit are older than others, and that they successively overlap each other as they are followed northward. This view has recently been enforced in detail by Mr. Harmer, who believes that three if not four distinct stages may be recognised in the Red Crag, not following each other vertically but horizontally, the oldest lying farthest south and containing

[1] Mr. Harmer has proposed still another name, "Gedgravian," from Gedgrave in Suffolk, where only this division of the Crag is present, *Q. J. G. S.* lvi. p. 707.

[2] C. Reid, *op. cit.* p. 19 *seq.* Mr. Harmer compares the deposit with the conditions found to exist on the Turbot bank off the north-east coast of Ireland, where by the strong sea-currents dead shells are heaped up in more sheltered parts at depths of 25 to 30 fathoms as a kind of "recent Crag," very similar in general character to the deposits of Suffolk and Norfolk. He thinks the sea in which the Coralline Crag was deposited lay less open to the north than the present North Sea, and was thus open to the southern mollusks from the Mediterranean basin.

the largest percentage of extinct and southern forms, while the proportion of recent and northern shells progressively increases northward among the later stages. These generalisations are embodied in the following subdivisions.[1] At the bottom lies (*a*) the Walton Crag, found only in Essex and distinguished by the marked southern aspect of its fauna, and especially the abundance of *Neptunea* (*Chrysodomus*) *contraria*. About 320 species of shells have been obtained from this deposit, of which the most characteristic are chiefly extinct or southern forms. They include *Cypræa* (*Trivia*) *avellana*, *Voluta* (*Aurinia*) *Lamberti*, *Nassa labiosa*, *Pleurotoma mitrula*, *Turritella incrassata*, *Natica hemiclausa*, *Trochus* (*Gibbula*) *cineroides*, *Cardita corbis* and *Astarte obliquata*. The northern or recent species, which become more or less common in the later stages of the Red Crag, are absent or rare at Walton. (*b*) Oakley Crag or zone of *Mactra* (*Spisula*) *obtruncata*, found inland from Walton, and recently shown by Mr. Harmer to contain an abundant fauna (upwards of 350 species and varieties) intermediate in age between the Walton and higher parts of the Red Crag. While these fossils still show a number of Coralline Crag and southern forms, they include a distinct assemblage of northern shells, such as *Trophon scalariformis*, *T. barvicensis*, *T. Sarsii*, *T. islandicus*, *Trochus* (*Calliostoma*) *formosus*, *Natica clausa*, *Scala grœnlandica*, *Mactra* (*Spisula*) *obtruncata*, *Tellina* (*Macoma*) *obliqua*, *Astarte compressa* and *Modiola modiolus*. (*c*) Newbourn Crag or zone of *Mactra* (*Spisula*) *constricta*. This zone, developed in Suffolk on the opposite or northern side of the River Stour, is characterised by the scarcity of some of the extinct or southern forms found on the Essex side of the estuary, such as *Columbella sulcata*, *Nassa elegans*, *Natica catenoides*, *Trochus* (*Gibbula*) *Adansoni*, and *Nucula lævigata*. On the other hand, it contains *Cardium angustatum*, *Mactra* (*Spisula*) *constricta*, *M.* (*Spisula*) *ovalis*, *Tellina* (*Macoma*) *obliqua*, *T. prætenuis* (the *Tellinæ* being a distinguishing feature), also *Nucula Cobboldiæ*, *Purpura lapillus*, *Scala grœnlandica*, *Admete viridula*, *Modiola modiolus*, *Astarte compressa*, &c. (*d*) The Butley Crag or zone of *Cardium grœnlandicum*, lies still farther north, and is marked by a further diminution of southern and a corresponding increase of northern types. The species *Tellina* (*Macoma*) *obliqua*, *T.* (*Macoma*) *prætenuis*, *Mactra* (*Spisula*) *constricta* and *Cardium angustatum* together form a large part of the deposit. The northern forms *Tritonofusus altus*, *Buccinum grœnlandicum*, *Natica pallida* (=*grœnlandica*) and *Cardium grœnlandicum* have been observed by Mr. Harmer to be more abundant here than in the older divisions.

The inorganic constituents of the Red Crag have been studied by Mr. J. Lomas. The pebbles consist chiefly of flints, but partly also of quartzite, sandstone, chert, and phosphatic nodules. The sands have been found to be made up mainly of quartz-grains, but to include also, like so many clastic sediments, derivative crystals or grains of zircon, rutile, kyanite, andalusite, corundum, garnets, ilmenite, leucoxene, tourmaline, biotite, muscovite, glauconite, microcline, orthoclase, labradorite, and albite.[2] It should be added that, besides the predominant marine fauna, a few land and fresh-water mollusks have been met with in the Red Crag, including *Pyramidula rysa*, *Helix* (*Hygromia*) *hispida*, *Limnæa palustris*, *Viviparus media*, *Planorbis marginatus*, *Pupa muscorum*, *Succinea putris*, and *Corbicula fluminalis*.[3]

Norwich Crag (Fluvio-marine or Mammaliferous Crag, Icenian of F. W. Harmer), extending over an area 40 miles long by 20 broad through the counties of Suffolk and Norfolk, is marked by a fauna which differs more from that of the Red Crag as a whole than the faunas of the several divisions of the latter do from each other.[4]

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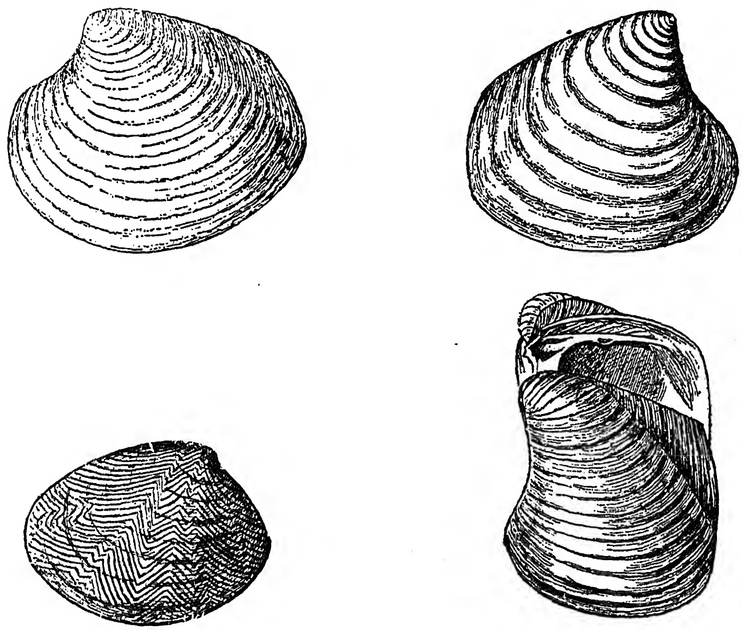
[1] See Mr. Harmer's paper, *Q. J. G. S.* lvi. p. 705, from which this information is given.

[2] *Q. J. G. S.* lvi. (1900), p. 738. See *ante*, pp. 173, 179.

[3] For a full account of the land and fresh-water mollusks of England, see A. S. Kennard and B. B. Woodward, *Proc. Malacolog. Soc.* iii. (1899), p. 187, iv. (1901), p. 183.

[4] Harmer, *op. cit.* p. 721.

The extinct and southern shells are now reduced to a small number of species, which are of rare occurrence in the deposit, the numerous forms that had survived through the time of the Red Crag having been exterminated by the geographical changes and the increasing cold that accompanied them. On the other hand, a number of northern forms not found in the Red Crag now make their appearance, particularly *Trophon Gunneri*, *T.* (*Buccinofusus*) *berniciensis*, *Velutina undata*, *Eumargarita grœnlandica*, *Rhynchonella* (*Hemithyris*) *psittacea*, *Nuculana pernula*, *Astarte elliptica* and *A. borealis*. With the fall in temperature there would seem to have been likewise a decrease in the variety of the marine fauna, if we may judge from the fact that the Norwich Crag has not yielded more than some 150 species in all, many of which are



c d

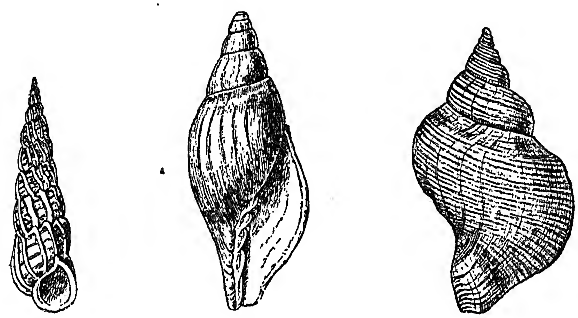
Fig. 485.—Pliocene Lamellibranchs.
a, Astarte borealis Chemn. (living northern species); *b*, Astarte Omalii, Laj. (extinct); *c*, Nucula Cobboldiæ, Sow. (extinct); *d*, Congeria subglobosa, Partsch. (extinct) (2/3).

excessively rare and most of the more abundant being common British forms. Of the most frequent shells three-fourths are recent and two-thirds are familiar denizens of the North Sea at the present day. Besides the predominant marine mollusks, the deposit has yielded thirty species of land and fresh-water shells, of which only three are extinct. These shells, like those of the Red Crag, have doubtless been washed off the land and carried out to the adjacent shell-banks on the sea floor. The name of "Mammaliferous" was given to the deposit from the large number of bones, chiefly of extinct species of elephant, obtained from it. The mammalian remains comprise both land and marine forms. Of the former are *Lutra Reevei*, *Gazella anglica*, *Cervus carnutorum*, *Equus stenonis*, *Mastodon arvernensis*, *Elephas antiquus*, *Microtus* (*Arvicola*) *intermedius*, *Trogontherium Cuvieri*. The marine mammals include *Trichechus Huxleyi* and *Delphinus delphis*. A few remains of sea-fishes have also been found, such as the cod and pollack.

The upper part of the Red Crag sometimes passes into a band, called from its prevailing mollusk the "Scrobicularia Crag." This band, which is probably a continuation of the Norwich Crag of Norfolk, is seen at Chillesford, in Suffolk, to pass upward without a break into the Chillesford Crag.[1]

Chillesford Crag.—Under this name is grouped a local series of micaceous sands with an overlying estuarine clay, containing as characteristic fossils *Turritella communis, Natica catena, Yoldia oblongoides, Y. lanceolata, Nucula Cobboldiæ, N. tenuis, Cardium edule, C. grœnlandicum, Mactra (Spisula) ovalis, Tellina (Macoma) calcarea (=lata), T. obliqua, Mya truncata.* The last-named shell may be seen upright in the position in which it lived.[2] Northern forms are still more prominent here, while a number of the common Red Crag forms have disappeared.

Weybourn Crag.—At Chillesford the Chillesford Crag passes insensibly upwards into a fine micaceous loam or clay containing a few shells and fish-vertebræ. Among the shells of this deposit are *Buccinum undatum, Purpura lapillus, Astarte compressa,*



a *b* *c*

Fig. 486.—Pliocene Gasteropods.
a, Scala grœnlandica, Chemn.; *b*, Voluta (Aurinia) Lamberti, Sow. (⅓); *c*, Neptunea (Chrysodomus) antiqua, Linn. (½).

Cyprina islandica, Lucina borealis, Nucula Cobboldiæ, N. tenuis, Tellina (Macoma) obliqua, Cardium grœnlandicum. Traced northwards the Chillesford Clay appears to pass into the deposit known as the Weybourn Crag, which is a band of laminated green and blue clays with loamy sand full of marine shells, well seen along the Norfolk coast to the west of Cromer. This member of the series has yielded 53 species and marked varieties of marine shells (*Tellina (Macoma) balthica*, specially abundant, *Saxicava arctica, Nucula Cobboldiæ, Mya arenaria, M. truncata, Cyprina islandica, Astarte compressa, A. sulcata, A. borealis, Turritella communis, Neptunea (Chrysodomus, Trophon) antiqua, Purpura lapillus, Bela (Pleurotoma) turricula, Littorina littorea, Buccinum undatum*, &c.), of which five, or 10·6 per cent, are extinct, and nine species are Arctic forms.

Forest-bed Group.[3]—One of the most familiar members of the English Pliocene

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[1] C. Reid, *op. cit.* p. 100. For an account of the vertebrate fauna of these deposits see E. T. Newton's monographs on "The Vertebrata of the Forest Bed Series of Norfolk and Suffolk" (1882) and "The Vertebrata of the Pliocene Deposits of Britain," in *Mem. Geol. Surv.*

[2] Harmer, *op. cit.* p. 723.

[3] On this group see Lyell, *Phil. Mag.* 3rd ser. xvi. (1840), p. 245, and his 'Antiquity of Man.' Prestwich, *Quart. Journ. Geol. Soc.* xxvii. (1871), pp. 325, 452; *Geologist*, iv. (1861), p. 68. John Gunn. 'Geology of Norfolk,' 1864. C. Reid, *Geol. Mag.* (2) vol. iv. (1877),

series is that to which the name of the "Cromer Forest-bed" has been given. It occurs beneath the cliffs of boulder-clay on the Norfolk coast, and was formerly believed to mark an old land-surface, with the stumps of trees *in situ*. More careful study, however, has shown that the stumps have all been transported to their present position, and lie not on an old soil, but in an estuarine deposit, perhaps that of the Rhine, which then spread over the low land that now forms the shallow southern half of the North Sea. It is now agreed that the group of strata known as the Forest-bed series may be divided into three groups, an upper and lower fresh-water bed separated by an estuarine layer. The general character of the strata comprised in this member of the Pliocene series is shown in the subjoined table :—

	Yoldia (*Leda*) *myalis* Bed (p. 1288).
Cromer Forest-bed Group.	Upper fresh-water Bed, consisting of sand mixed with blue clay (2-7 feet) and enclosing twigs and shells (*Succinea putris*, *Sphærium* (*Cyclas*) *corneum*, *Valvata piscinalis*, *Bithinia tentaculata*, *Pisidium amnicum*, &c.).
	Forest-bed (estuarine), composed of laminated clay and lignite, alternating gravels and sands with pebbles, cakes of peat, branches and stumps of trees, and mammalian bones, &c. (ranging up to more than 20 feet in thickness).
	Lower Fresh-water Bed, made up of carbonaceous, green, clayey silt full of seeds, with laminated lignite and loam.
	Weybourn Crag.

The vegetation preserved in this group of strata embraces at least 56 species of flowering plants, two of which, the water chestnut and spruce fir, do not appear to have belonged to the British flora since the Glacial period ; the others are nearly all still living in Norfolk. The royal fern (*Osmunda regalis*) formed part of this pre-glacial vegetation. The variety of forest-trees points to a mild and moist climate ; they include the maple, sloe, hawthorn, cornel, elm, birch, alder, hornbeam, hazel, oak, beech, willow, yew, pine, and spruce. The land and fresh-water shells number 58 species, whereof five appear to be extinct (*Limax modioliformis*, *Nematura* (*Nematurella*) *runtoniana*, *Viviparus glacialis*, *V. media*, *Pisidium astartoides*) and five no longer live in Britain (including *Bithynella* (*Hydrobia*) *Steinii*, *Valvata fluviatilis*, *Corbicula fluminalis*). The known marine shells in the Forest-bed series are so few in number (19 species) that they do not afford a satisfactory basis for comparison with other parts of the Pliocene formations. Some of them may have been washed out of the Weybourn Crag below, and they are all common Weybourn Crag fossils, including several extinct species (*Melampus pyramidalis*, *Tellina* (*Macoma*) *obliqua*, *Nucula Cobboldiæ*). They indicate that the climate of the time when they lived was probably not greatly different from that of the present day. Fourteen species of fishes have been recognised (*Platax Woodwardi*, cod, and tunny among marine forms, also perch, pike, barbel, tench, and sturgeon among fluviatile kinds). The fauna also includes two reptiles (*Tropidonotus natrix*, *Vipera berus*), four amphibians (frogs and tritons), five birds (eagle-owl, cormorant, wild goose, wild duck, shoveller duck), and fifty-nine mammals. These last-named fossils give the Forest-bed its chief geological interest. They include a few marine forms—seals, whales, walrus, and a large and varied assemblage of terrestrial and river-haunting forms, such as carnivores—*Machærodus*, *Canis lupus*, *C. vulpes*, *Hyæna crocuta*, *Ursus spelæus*, *Mustela martes*, *Gulo luscus*, *Lutra vulgaris ;* ungulates—*Bison bonasus*, *Ovibos moschatus*, *Alces latifrons*, *Cervus elaphus* (and nine other species), *Hippopotamus amphibius*, *Sus scrofa*, *Equus caballus*, *E. Stenonis*, *Rhinoceros etruscus*, *Elephas antiquus*, *E. meridionalis ;* rodents—*Microtus* (*Arvicola*) *arvalis*, *Mus sylvaticus*, *Castor fiber*, *Trogontherium Cuvieri ;* insectivores—*Talpa europæa*, *Sorex vulgaris*, *S. pygmæus*, *Myogale moschata*. The contrast between this strange collection of animals and the familiar aspect of the plants

p. 300 ; vii. (1880), p. 548 ; "Geology of the Country around Cromer," in *Mem. Geol. Surv.* 1882 ; "Pliocene Deposits of Britain," in *Mem. Geol. Surv.* 1890 ; 'The Origin of the British Flora,' 1899 ; and E. T. Newton's monographs cited in a foregoing note.

associated with them was long ago remarked by Lyell.[1] The most abundant and conspicuous forms are the three species of elephant, while the hippopotamus and rhinoceros are of common occurrence. Of the two horses one is extinct, the bison and wild boar have survived elsewhere, while the whole of the remarkably numerous species of deer have disappeared, with the single exception of the red-deer, which would doubtless have likewise been exterminated long ago had it not been protected for purposes of sport. The carnivores embraced also living and extinct forms, for the long-vanished machaerodus haunted the same region with our still surviving fox, otter, and marten, and with other animals which, like the hyaena, wolf, and glutton, though no longer found in Britain, continue to live elsewhere. The total species of land mammals (exclusive of bats) found in the Forest-bed is 45, while the corresponding series of the living British fauna numbers only 29 species. Of the 30 large land mammals found in this deposit, only three are now living in Britain, or have died out there within the historic period, and only six species have survived in any part of the world.[2]

The Cromer Forest-bed is succeeded on the Norfolk coast by some sands and gravels of which the true position in the series of formations has not yet been definitely fixed. They include two distinct members, though their precise relations to the Crag below and the glacial materials above are still not satisfactorily settled. The lower band is known as the *Yoldia* (*Leda*) *myalis* bed, and the upper as the Arctic fresh-water bed. The former may be provisionally placed with the rest of the Pliocene formations of Norfolk. The latter can hardly be separated from it, and would not be so separated but for the remarkable character of its few included fossils. These indicate such a great increase of cold as to show that the conditions of the Glacial period must now have set in. Hence the Arctic fresh-water bed is classed with the Pleistocene series.

Yoldia (Leda) myalis Bed.—This band, nowhere more than 20 feet in thickness, consists of false-bedded loamy sand, loam or clay, and a little gravel, and lies sometimes on the Forest-bed, sometimes on the Weybourn Crag. This unconformability may mark a considerable interval of time, during which the floor of the estuary seems to have subsided, perhaps as much as fifty feet. Among the scanty organisms of the deposit, the following may be mentioned: *Buccinum undatum*, *Littorina littorea*, *L. rudis*, *Purpura lapillus*, *Neptunea* (*Chrysodomus*, *Trophon*) *antiqua*, *Astarte borealis*, *Cardium edule*, *Cyprina islandica*, *Yoldia* (*Leda*) *myalis*, *Mya truncata*, *Mytilus edulis*, *Ostrea edulis*, *Tellina* (*Macoma*) *balthica*. Some of these shells (the *Astarte*, *Yoldia*, and *Mya*) are found with the valves united in the position of life. The *Yoldia* is an Arctic species not known in any of the underlying formations.

Arctic Fresh-water Bed.—Reference may be made here to this deposit, which is so intimately linked with that last described. It consists of stiff blue loam, clay, and sand, sometimes more than two feet thick, like the deposits of transient floods. Its plants include a number of mosses, with the dwarf Arctic birch and willow (*Betula nana* and *Salix polaris*, Fig. 490)—a vegetation wherein trees seem to have as completely disappeared as in the Arctic lands. It may indicate a lowering of temperature by about 20° Fahr.—"a difference as great as between the south of England and the North Cape at the present day, and sufficient to allow the seas to be blocked with ice during the winter, and to allow glaciers to form in the hilly districts."[3] Among the plants a few land-shells have been found, such as *Succinea putris*, *S. oblonga*, *Pupa muscorum*, together with some wing-cases of beetles.

Various pebble-gravels occur in different parts of southern England, the true stratigraphical position of which is still undetermined. They are generally unfossiliferous. Some parts of them may be Pliocene. In the south-west, at Dewlish in Dorset, a

[1] 'Antiquity of Man,' 1st edit. (1863), p. 216. See also C. Reid, 'Pliocene Deposits of Britain,' p. 182.

[2] C. Reid, 'Pliocene Deposits of Britain.'

[3] C. Reid, *op. cit.* p. 198.

deposit of sand and gravel has yielded a number of elephant bones and teeth referred to *Elephas meridionalis*, and pointing to an Upper Pliocene age.

Belgium and Holland.—The sea in which the English Pliocene deposits were laid down probably extended across Belgium, Holland, and the extreme north of France, but no trace of its presence has yet been found eastwards in Germany. In Belgium the base of the Pliocene is found to rest with a strong unconformability on all older deposits, even on the Miocene sands (Bolderian and Anversian). The older Pliocene group consists chiefly of sand, and has been named Diestian from the locality where it is typically developed. At Antwerp, Utrecht, and other places it has yielded a large assemblage of fossils (190 species), all of which save 22 occur in the English Coralline Crag and Lenham beds. This horizon may be paralleled with the Plaisancian group of southern France and Italy. Above the Diestian sands comes the group known as Scaldesian,[1] which is likewise made up mainly of sands enclosing a fauna closely resembling that of the lower part of the English Red Crag (Walton Crag).[2] After these marine sands were accumulated, the Belgian area appears to have participated in the upward movement that affected the south-east of England; at all events the overlying members of the English Crag are not found in that region. But farther north the terrestrial movement was in a contrary direction, the sea-bottom sank during Pliocene and Pleistocene time, until many hundreds of feet of sedimentary deposits were laid down over the site of Holland. This succession of events has been made clear by a series of deep borings in that country. At Utrecht the strata were pierced to a depth of 1198 feet without reaching the base of the Pliocene deposits. There appears to be a general inclination and a progressive thickening of the strata in a northerly direction, so that a horizon of land and fresh-water shells, which at Utrecht lies between 521 and 542 feet below the surface, was formed farther north, at Amsterdam, at about 768 feet. According to Mr. Harmer, the greater part of these Dutch Pliocene deposits are newer than the Belgian Scaldesian stage. From the fossils obtained at the different borings he has advocated the recognition of another formation or group of Newer Pliocene strata lying upon, and passing down into the Scaldesian, but separable from that division by its smaller proportion (30 per cent) of extinct shells, its decrease in the number of southern forms (6·8 per cent) and its increase in northern species (13·7 per cent). For this formation, which is 202 feet thick at Utrecht and more than 450 feet at Amsterdam, he has proposed the name of "Amstelian." Its shells are among the most abundant and characteristic species of the upper horizons of the English Crag.[3] Towards its upper limit, beneath the overlying Pleistocene accumulations, it contains land and fresh-water shells, which probably indicate that subsidence had been arrested, and that the sea over Holland, like that over East Anglia, gradually shallowed and gave place to the ancient estuary of the Rhine. None of the latest Pliocene subdivisions have been met with in Holland or in Belgium. In the latter country various deposits, of which the precise horizons have not been determined, have yielded a large number of bones of marine mammalia, including seals, dolphins, and numerous cetaceans, as well as remains of fishes (*Carcharodon*, *Lamna*, *Oxyrhina*, &c.).

France.—In the north of this country, unfossiliferous sands which cap the hills between Boulogne and Calais at heights of 400 or 500 feet, and stretch eastwards into French Flanders, are believed to be continuations of the Lenham and Diestian group. In the north-west, many larger scattered patches of Pliocene deposits are widely distributed over Brittany and the adjacent districts. They include marine marls, clays,

[1] The upper part of this stage has been separated by M. Vincent as a slightly newer zone, named "Poederlian."

[2] For a comparison of the faunas of the two formations see F. W. Harmer, *Q. J. G. S.* lii. (1896), p. 756. He finds that 90 species which are abundant in the Walton Crag, including 28 extinct, 19 southern and 2 northern, are also abundant in the Belgian beds.

[3] *Op. cit.* p. 763.

and sands, with *Nassa prismatica*, *N. mutabilis*, *Voluta* (*Aurinia*) *Lamberti*, *Terebratula grandis*, and show a submergence of the lower grounds to the extent of more than 100 feet. Similar evidence of submergence under the Pliocene sea is found along the borders of the Golfe du Lion and the Mediterranean coast farther east. The deposits then formed lie unconformably on every series older than themselves, and bear witness to a subsequent elevation of that region to an extent, in some places, of 1150 feet above the present sea-level. The marine strata extend up the valley of the Rhone, nearly as far as Lyons, and they mark the final deposits of the sea in that part of the mainland of Europe. They cap the plateaux and rise towards the north and west, indicating a maximum of uplift in that direction. Their upper parts contain lacustrine and terrestrial organisms, and similar evidence of land is found on their borders near what was probably the old shore-line. The marls of Hauterives (formerly regarded as Miocene) are remarkable for their beds of coarse conglomerate, which represent some of the torrential deposits swept down from the neighbouring hills. These marls contain land and fresh-water shells. Farther east, in the Alpes Maritimes, the Pliocene series assumes a more definitely marine character. At the base lies a thick mass of blue clays, well seen at many places along the coast of the French Riviera. These strata contain *Ostrea cochlear*, *Pecten cristatus*, *Arca* (*Anadara*) *diluvii*, *Nassa semistriata*, *Conus antediluvianus*, *Terebratula ampulla*, &c. Above them lie some yellow clays with similar fossils, followed by a limestone with foraminifers, oysters, and other marine organisms, over which comes a thick conglomerate marking the coarse alluvium of torrents from the neighbouring hills. At the top the usual indications of fresh-water deposits are seen.

In the centre of the country the Pliocene formations are all of subaerial, lacustrine, or fluviatile origin, and have preserved an interesting and varied record of the terrestrial plant and animal life of the time. In the volcanic districts they are found beneath some of the younger lavas, and have thus been protected from the denudation which has so largely removed the contemporaneous records elsewhere. The trachytic conglomerate of Perrier (Issoire) and the ossiferous deposits of other localities in Auvergne have yielded an abundant fauna, in which the apes are absent, the antelopes have dwindled in size and number, the deer have grown very abundant, true elephants for the first time appear, associated with a species of hippopotamus, nearly if not quite identical with the living African one, two kinds of hyæna, and the hipparion and machærodus that had survived from earlier times. This fauna indicates a decided change of climate to a more temperate character. Among the volcanic products of Haute Loire remains of *Mastodon arvernensis*, *Rhinoceros leptorhinus*, *Equus stenonis*, and *Machærodus pliocænus* have been collected.

Putting together the evidence derivable from the succession of mammalian remains in the scattered Pliocene fresh-water and terrestrial deposits of France, palæontologists have grouped these accumulations in the following order:[1]

Upper (Arnusian, Sicilian). Arranged in what appears to be the descending order, the newest deposits belonging to this stage are those of Sainzelles (Puy), rather earlier than which come the famous gravels of Perrier. Still older are the upper parts of the fluvio-lacustrine beds of Montpellier, the upper portion of the volcanic group of Coupet, the deposits of Vialette (near Le Puy), the fluviatile clays and sands of Chagny (Saône), and the Mastodon sands of Le Puy.

In this stage *Hipparion* disappears and is replaced by *Equus stenonis*, *Rhinoceros etruscus* succeeds *R. leptorhinus*. The proboscidea are represented by the last of the European mastodons, *M. arvernensis* and *M. borsoni*. *Elephas meridionalis*, the great southern elephant and precursor of the mammoth, is found in the valley of the Saône and ranges into Italy. It is in the Val d'Arno that the mammalian fauna of this stage is most typically displayed (p. 1293).

Middle (Astian). Here come the grey, siliceous, fluvio-lacustrine sands of Rous-

[1] See especially H. F. Osborn, *Ann. New York Acad. Sci.* xiii. (1900), p. 30, from which this summary is taken.

sillon[1] (25 metres), containing a fauna like that of the Montpellier deposits, of which the lower portion, consisting of yellow marine sands (50 metres), is placed in this stage. Here also are grouped the fluviatile deposits of Perpignan, the calcareous tuff of Meximieux (with its abundant flora presenting resemblances to those of the Canary Islands and Mongolia), and the sands of Trevoux (Saône), containing *Viviparus*, *Melanopsis*, *Palæoryx*, *Rhinoceros leptorhinus*, *Mastodon arvernensis*.

In this stage characteristic species not found at Pikermi are the Rhinoceros and Mastodon just named, together with *Tapirus arvernensis* and *Ursus arvernensis*. Forms having affinities to some of those found in the Messinian or Pikermi deposits are *Hipparion*, *Palæoryx* and *Hyænarctos*, the Asiatic apes *Dolichopithecus* and *Semnopithecus*; the African antelopes, *Palæoryx cordieri* and *P. boodon*.

Lower. The terrestrial mammals of the Plaisancian stage are best displayed in the lignites of Casino (Tuscany), where are found *Hipparion*, *Sus erymanthius*, *Antilope Massoni*, *Tapirus priscus*, *Semnopithecus monspessulanus* and other forms. The Pikermi deposits classed by some writers as Miocene are by others placed at the base of the Pliocene series (Messinian) (p. 1294). With them may be classed the ossiferous breccias of Mont Léberon and Cucuron (Vaucluse), and the Eppelsheim gravels near Darmstadt.

In this stage distinctive mammalian types are *Pliohylobates* (Eppelsheim), *Hystrix* (Pikermi), *Pliohyrax* (Samos), *Hipparion gracile*. *Aceratherium incisivum* of Eppelsheim succeeds *A. tetradactylum* of Sansan; *Rhinoceros Schleiermacheri* may be a large successor of *R. sansaniensis*; *R. Goldfussi* (Eppelsheim) a successor of *R. brachypus* (Grive St. Alban). *Dinotherium giganteum* replaces *D. bavaricum*. The mammalia show a marked evolution beyond the Upper Miocene types.

Italy.—As the Pliocene series is traced eastwards into Italy its lacustrine intercalations disappear and it becomes mainly a marine formation, which is so amply developed there that it might be taken as typical for the rest of Europe. Along both sides of the chain of the Apennines it forms a range of low hills, and has been named from that circumstance the "sub-Apennine series." In the Ligurian region, according to C. Mayer, it consists of the following groups in ascending order: 1, Messinian[2] (= Zanclean of Seguenza), composed of (*a*) marls, conglomerates (the torrential débris of the streams from the adjacent mountains), and molasse (65 feet), with *Cerithium pictum*, *C. rubiginosum*, *Venus multilamella*, *Pecten cristatus*, *Turritella communis*, *T. subangulata*: (*b*) gypsiferous marls, limestones, dolomites (320 feet, Congeria group), traceable along the range of the Apennines as far as Girgenti in Sicily by its well-known gypsum and sulphur zone, and containing *Turritella subangulata*, *Natica helicina*, *Pleurotoma dimidiata*, *Congeria simplex*, *C. rostriformis*, &c.; (*c*) gravels and yellow marls, with beds of lignite (upwards of 300 feet). To the Messinian group belong the conglomerates, tripoli deposits (with land plants, insects, fishes, &c.) of Leghorn, and the lacustrine deposits with land-plants (palms, &c.) of Pavia and of Sinigaglia on the Adriatic. 2, Astian, composed, at the foot of the Ligurian Apennines, of two groups, (*a*) blue marls with *Dentalium sexangulare*, *Turritella communis*, *T. tornata*, *Murex trunculus*, *Natica millepunctata*, &c.; (*b*) yellow sands with few fossils (300 feet and more).[3] More recently Professor Sacco has estimated the whole series in the central portion of the northern Apennines to have a thickness of nearly 1500 feet, which he groups as in the subjoined table:[4]—

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[1] See C. Depéret, *Ann. Sci. Géol.* 1885; "Les Animaux Pliocènes du Roussillon," *Mém. Soc. Géol. France*, 1890.

[2] This stage is by some authors placed at the top of the Miocene series (Pontian stage). On the Italian Pliocene see the paper by C. De Stefani cited p. 1271.

[3] C. Mayer, *B. S. G. F.* (3), v. 292.

[4] F. Sacco, 'Il Bacino Terziario del Piemonte,' Milan, 1889. See also De Stefani, *Atti. Soc. Tosc. Sci. Nat.* 1876-84.

Villafranchian (100 metres).	Fluvio-lacustrine alluvial sands, marls, clays, and conglomerates, with shells indicating a warm, moist climate, *Rhinoceros etruscus*, *Mastodon arvernensis*, &c.
Astian (100 metres).	Yellow sands and gravels, rich in littoral, marine or estuarine fossils.
Plaisancian (150 metres).	Marls and sandy clays with abundant marine fossils, from one-third to one-half of the shells belonging to living species.
Messinian (100 metres).	Sandy and clayey marls with seams of gypsum and limestone marking alternations of brackish-water and marine conditions. The shells include species of *Dreissensia*, *Adacna*, *Cyrena*, *Neritodonta*, *Melania*, *Melanopsis*, *Hydrobia*, &c. Some of the marls are full of leaves (*Thuja*, *Phragmites*, *Myrica*, *Quercus*, *Castanea*, *Fagus*, *Ulmus*, *Ficus*, *Liquidambar*, *Laurus*, *Sassafras*, *Cinnamomum*, *Rhamnus*, &c.).

At Rome the younger Pliocene series is well seen, having at its base a blue pteropod marl containing *Pecten rimulosus*, *P. cristatus*, *Nassa semistriata*, *Dentalium elephantinum*, &c., succeeded by yellow sands (Astian of Monte Mario), with *Pecten latissimus*, *P. flabelliformis*, *P. jacobæus*, *Cardium rusticum*, *Anomia ephippium*, *Cyprina islandica*. Higher still come sands, gravels, and lacustrine clays, containing *Elephas meridionalis* or *antiquus*, *Rhinoceros megarhinus*, *Hippopotamus major*, *Equus stenonis*, *Sus scrofa*, *Cervus elaphus*, *Bos primigenius*, wolf, fox, brown bear, hyæna, lion, lynx, wild cat, &c. An interesting feature of these deposits is presented by the evidence of contemporaneous and increasingly vigorous volcanic action which they display. The blue clay at the base was probably laid down in a sea of some little depth, but it was followed by sandy and gravelly detritus and by layers of volcanic tuff, all of which were accumulated in shallower water still connected with the sea, as is shown by the occurrence of abundant shells of *Pectunculus*, &c. Among the clastic sediments volcanic minerals, particularly augite and leucite, are abundant, and the tuffs are full of lumps of dark pumice and lapilli. Subsequent brackish-water conditions are indicated by the enclosed shells, and in the upper parts of the series land and fresh-water species show that the sea-floor had now been raised into land. Thus, like Vesuvius, Etna, and Bolsena, the Latian volcanoes began with submarine eruptions, and gradually built up their structure on an upraised sea-floor of volcanic material.[1]

In Sicily a similar threefold grouping has been made by Seguenza, who has traced the same arrangement throughout a large part of the mainland. The lowest group, named by him Zanclean, consists of marls and light-coloured limestones. The Plaisancian follows in a group of blue clays or marls, while the succeeding Astian consists of yellow sands. Of these stages the first is characterised by a fauna of which nearly $\frac{9}{10}$ are peculiar species, and only 85 out of 504 species, or about 17 per cent, belong to living forms which are nearly all found in the Mediterranean. Some of the common species of the deposit are *Terebratulina caput-serpentis*, *Rhynchonella bipartita*, *Dentalium triquetrum*, *Pecten (Janira) flabelliformis*, *Limopsis aurita*, *Nuculana dilatata*, *N. striata*, *Modiola phaseolina*. Tropical genera are well represented among the shells of the Italian older Pliocene beds, while some of the still living Mediterranean genera occur there more abundantly, or in larger forms than on the present sea-bottom. The newer Pliocene deposits attain in Sicily a thickness of 2000 feet or more, rising to a height of nearly 4000 feet above the present sea-level, and covering nearly half of the island. To this series, though possibly it should be regarded as, at least in part, Pleistocene, is assigned a yellowish limestone, sometimes remarkably massive and compact, and 700 or 800 feet thick, yet full of living species of Mediterranean shells, some of which even

[1] The latest and fullest account of the geology of the Roman Campagna and of its abundant younger Pliocene fauna will be found in Professor A. Portis' 'Contribuzioni alla Storia Fisica del Bacino di Roma,' vol. i. (1893), vol. ii. (1896), Part vi. in *Boll. Soc. Geol. Ital.* xix. (1900), Fasc. 1. The volcanic geology of the northern Apennines is discussed by C. De Stefani, *Boll. Soc. Geol. Ital.* x. (1891), pp. 449-555.

retain their colour, and a part of their animal matter. As above remarked, it was during the accumulation of the Pliocene strata that the later volcanic history of Italy began, the first stages being submarine eruptions, which were followed by the piling-up of the present sub-aerial cones upon the upraised Pliocene sea-bottom.

There is distinct evidence of a lowering of the climate of Southern Europe during the deposition of the Italian Pliocene series. Not only did many of the distinctively southern types of shells gradually disappear from the Mediterranean, but others of markedly northern character, such as species of *Astarte*, took their place. The Italian Pliocene deposits, while chiefly of marine origin, contain also among their higher members lacustrine or fluviatile strata, in which remains of the terrestrial flora and fauna have been preserved. In the upper part of the valley of the Arno an accumulation of lacustrine beds attains a depth of 750 feet. The older portion consists of blue clays and lignites, with the abundant vegetation above referred to (p. 1275). The upper 200 feet consist of sands and a conglomerate ("sansino"), and have yielded numerous remains of mammals, including *Macacus florentinus*, *Mastodon* (*Tetralophodon*) *arvernensis*, *Elephas meridionalis*, *Rhinoceros etruscus*, *Hippopotamus amphibius* (*major*), *Hyæna* (3 sp.), *Felis* (3 sp.), *Ursus etruscus*, *Machærodus* (3 sp.), *Equus stenonis*, *Bos etruscus*, *Cervus* (5 sp.), *Palæoryx*, *Palæoreas*, *Castor*, *Hystrix*, *Lepus arvicola*.[1] These strata are sometimes grouped as a higher zone of the Pliocene series under the name of Arnusian.[2]

Germany.—The absence of marine Pliocene formations in Germany has been already referred to. Among the lacustrine and fluviatile deposits of the period, however, numerous remains of the terrestrial flora and fauna have been preserved. One of the most celebrated localities for the discovery of these remains lies in the Mainz basin, where at Eppelsheim, near Worms, above the Miocene beds, described on p. 1268, a group of sands and gravels with lignite (Knochensand), from 20 to 30 feet thick, has yielded a considerable number of mammalian bones. Among these the *Dinotherium giganteum* occurs, showing the long survival of this animal in Central Europe; also *Mastodon angustidens*, *Rhinoceros incisivus*, and other species, *Hipparion gracile*, several species of *Sus*, five or more of *Cervus*, some of *Felis*, with *Machærodus* and *Dryopithecus*.

Interesting collections of the terrestrial fauna of the period have been preserved in the calcareous tuffs of mineral springs in different parts of Germany. Besides numerous remains of land-plants, large numbers of land and fresh-water shells have been obtained from these deposits, which in some cases point to a colder climate than now exists. In the Franconian Alb, for instance, the occurrence of alpine and northern European forms of land-shells (*Patula solaria*, *Clausilia densestriata*, *C. filograna*, *Helix vicina*, *Pupa pagodula*, *Isthmia costulata*) has been noted. The mammals include many extinct as well as some still living forms (*Elephas antiquus*, *Rhinoceros Merkii*, *Sus scrofa*, *Cervus elaphus*, *Capreolus caprea*, *Bos primigenius*, *Equus caballus*, *Ursus spelæus*, *Meles vulgaris*, *Hyæna spelæa*).[3]

Vienna Basin.—In consecutive conformable order above the Miocene strata described on p. 1268, come the highest Tertiary beds of this area, referred to the Pliocene period. The lowest group of strata is known by the name of the "Congeria stage," from the abundance of the molluscan genus *Congeria*[4] (Fig. 485). Higher up comes the

[1] C. J. Forsyth Major, *Q. J. G. S.* xli. (1885), p. 1.

[2] Mr. C. Reid suggests that the lignite deposits of the Val d'Arno (with *Tapirus*) may be much older than the rest of the lacustrine strata (with *Mastodon* and *Elephas*). A large proportion of the plants in them is extinct, and the tapir is the only animal whose remains are found in them. They may possibly be even Miocene.

[3] F. von Sandberger, 'Land und Süsswasser Conchylien der Vorwelt,' 1875, p. 936; *Sitzb. Bayer. Akad.* xxiii. (1893) Heft 1; Hellmann, *Palæontographica*, suppl.

[4] For an account of this genus and its relation to *Dreissensia*, consult P. Oppenheim. *Z. D. G. G.* xliii. (1891), p. 923.

Belvedere-schotter or Thracian stage with, in some places, the lacustrine Levantine stage. The leading characters of these groups are expressed in the subjoined table:

2. Thracian Stage or Belvedere-Schotter—coarse fluviatile conglomerate or gravel and sand composed of quartz and other pebbles, yielding bones of large mammals, like those of Eppelsheim, *Mastodon (Tetralophodon) longirostris*, and *Dinotherium giganteum* being especially frequent, together with species of *Anthracotherium*, *Hipparion*, and *Rhinoceros*. The yellow micaceous sand, forming the lower member of the stage, contains in its more compact portions abundant terrestrial leaves, silicified tree-trunks and shells of *Unio*. These strata resemble part of the alluvia of a large river. Their name is taken from the Belvedere in Vienna, where they are well developed. In some parts of the Vienna basin the Congeria stage is immediately overlain by fresh-water limestones with *Helix* and *Planorbis*, which have been called the Levantine stage. This lacustrine facies attains a much greater development in Croatia, Slavonia, and Roumania.
1. Congeria Stage (Inzersdorf Tegel)—a tolerably pure clay reaching a depth of often more than 300 feet. This deposit, the youngest Tertiary layer that is widely distributed over the Vienna basin, points to continued and general submergence. The facies of its fossils, however, shows that the water no longer communicated freely with the open sea, but, like the corresponding strata in the Mediterranean region, seems rather to have partaken of a brackish or Caspian character. Among the conspicuous mollusks are *Congeria subglobosa*, *C. Partschi*, *C. triangularis*, *C. spathulata*, *C. Czjzeki*, *Cardium carnuntinum*, *C. apertum*, *C. conjungens*, *Unio atavus*, *U. moravicus*, *Melanopsis martiniana*, *M. impressa*, *M. vindobonensis*, *M. Bouéi*. The mammals include *Mastodon (Tetralophodon) longirostris*, *M. (Trilophodon) angustidens*, *Dinotherium giganteum*, *Aceratherium incisivum*, *Hipparion gracile*, antelope, pig, *Machaerodus cultridens*, *Ictitherium (Hyaena) hipparionum*. The flora includes, among other plants, conifers of the genera *Glyptostrobus*, *Sequoia*, and *Pinus*, also species of birch, alder, oak, beech, chestnut, hornbeam, liquidambar, plane, willow, poplar, laurel, cinnamon, buckthorn, with the Asiatic genus *Parrotia*, the Australian proteaceous *Hakea* (Fig. 478), and the extinct tamarind-like *Podogonium*.

In other parts of the Austro-Hungarian empire interesting evidence exists of the gradual uprise of the sea-floor during later Tertiary time and the isolation of detached areas of sea, so that the south-east of Europe must then have presented some resemblance to the great Aralo-Caspian depression of the present time. The Congerian stage brings before us the picture of an isolated gulf gradually freshening, like the modern Caspian, by the inpouring of rivers; but on both sides of the Carpathian range there were bays nearly cut off from the main body of water, and exposed to so copious an evaporation without counterbalancing inflow that their salt was deposited over the bottom. Of the Transylvanian localities, on the south side of the mountains, the most remarkable is Parajd, where a mass of rock-salt has been accumulated, having a maximum of 7550 feet in length, 5576 feet in breadth, and 590 feet in depth, and estimated to contain upwards of 10,595 millions of cubic feet. On the northern flank of the Carpathian Mountains, near Cracow, lie the famous and extensive salt-works of Wieliczka, with their massive beds of pure and impure rock-salt, gypsum, and anhydrite, some of the strata being full of fossils characteristic of the upper zones of the Vienna basin.

The south-east of Europe, during later Tertiary time, was the scene of abundant volcanic action, and the outpourings of trachyte, rhyolite, basalt, and tuff were especially abundant over the low districts to the south of the Carpathian chain.

Greece.—A remarkable series of mammalian remains brought to light from certain hard red clays alternating with gravels at Pikermi, between Athens and Marathon, was carefully worked out by M. Gaudry.[1] The deposit in which these remains lie has since

[1] 'Animaux fossiles et Géologie de l'Attique,' 4to, 1862, with volume of plates; *B. S. G. F.* xiv. (1885-86), p. 288. See also Roth and Wagner, *Abhandl. Bayer. Akad.* vii.

been ascertained to be widely distributed in Attica. Mr. Smith Woodward has recognised it in Northern Eubœa, 60 miles to the north of Pikermi, containing there similar fossils. He describes the red marl or clay as sometimes full of land and fresh-water shells, and the bones as lying in great confusion, whole specimens and splintered bones being huddled together on successive platforms. Since many of the bones, such as those of the feet and limbs, are still in their natural positions, and were obviously held together by ligaments when they were buried, he infers that the animals were hurried by torrential floods through thickets or tree-obstructed water-courses before being finally entombed, and that accompanying stones in rapid motion may have been partly instrumental in the fracturing of the bones. The fauna here disinterred includes a monkey (*Mesopithecus*) intermediate between the living *Semnopithecus* of Asia and the Macaques. The carnivores are represented by *Simocyon, Mustela, Promephitis, Ictitherium*—a genus allied to the modern civet—*Hyænictis, Hyæna, Machærodus*, and several species of *Felis;* the rodents by *Hystrix*, allied to the common porcupine; the

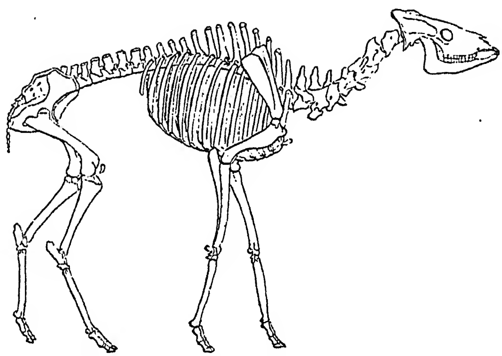

Fig. 487.—Helladotherium Duvernoyi, Gaudry ($\frac{1}{50}$).

edentates by the gigantic *Ancylotherium;* the proboscideans by *Mastodon* and *Dinotherium;* the perissodactyle ungulates by *Rhinoceros* (several species), *Aceratherium, Leptodon, Hipparion;* the artiodactyle ungulates by a gigantic wild boar (*Sus erymanthius*), *Camelopardalis*, of the same size as the living giraffe, *Helladotherium*—a form between the giraffe and the antelopes, three species of true antelope, *Palæotragus*—an antelope-like animal, *Palæoryx*, somewhat like the living African gemsbok, and *Palæoreas*, allied to the African eland and the gazelles, *Gazella*—a true gazelle, and *Dremotherium*, probably a hornless ruminant like the living chevrotains. A few remains of birds have also been met with, including a *Phasianus*, related to a pheasant, a *Gallus*, smaller than our common domestic fowl, a *Grus*, closely related to the living crane; also bones of a tortoise (*Testudo*) and a saurian (*Varanus*). This fauna is remarkable for the extraordinary abundance of its ruminants, the colossal size of many of the forms, such as the giraffe and *Helladotherium*, the singular rarity of the smaller mammals, the marked African facies which runs through the whole series, and the number of transitional

(1854). T. Fuchs, *Denksch. Akad. Wien*, xxxviii. (1877) 2e Abtheil, p. 1; *Bull. Com. Geol. Ital.* ix. (1878), p. 110. W. T. Blanford, Address, *Geol. Sect. Brit. Assoc.* 1884. W. Dames (*Z. D. G. G.* xxxvi. 1883, p. 9) has added a species of *Cervus* and one of *Mus* to the previously known Pikermi forms. Further collections have recently been made by Mr. A. Smith Woodward for the British Museum (*Geol. Mag.* 1901, p. 431), but without adding materially to the number of forms previously known, though much new information has been obtained by him in regard to the species already described.

types which it contains. Out of the 31 genera of mammals which M. Gaudry obtained, 22 are extinct. The Pikermi beds have been classed as Upper Miocene, but the occurrence of characteristic marine Pliocene species of shells below them (*Pecten benedictus*, *Spondylus gæderopus*, *Ostrea lamellosa*, *O. undata*) justifies their being placed in a later stage of the Tertiary series. They are shown by Fuchs to form part of the Pliocene series of Attica, and lie in the highest part of that series.

Samos.—In an irregular deposit of gravels, sandstones, and marls in the island of Samos, Dr. Forsyth Major has discovered a large assemblage of vertebrate remains of an age similar to that of the Pikermi strata. Among the fossils obtained by him are many of the same species as are found at the Greek locality, such as *Promephitis Larteti*, *Mustela palæattica*, *Lycyæna Chæretis*, *Ictitherium robustum*, *I. hipparionum*, *Ancylotherium Pentelici*, *Mastodon Pentelici*, *Rhinoceros pachygnathus*, *Hipparion mediterraneum*, *Sus erymanthius*; seven antelopes, *Palæoreas Lindermayeri*, *Gazella brevicornis*, *Palæoryx Pallasii*, and two others. Besides these, there are some half-dozen antelopes of African types, and true edentates, *Orycteropus Gaudryi*, *Palæomanis Neas*, a new genus of gigantic ruminants, *Samotherium*, belonging to the family of the giraffes, and recalling the *Helladotherium* of Pikermi, and an ostrich (*Struthio Karatheodoris*).[1]

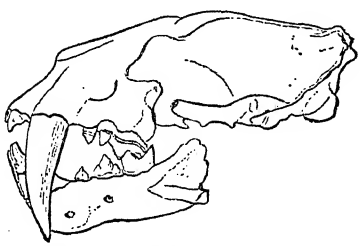

Fig. 488.—Head of Machaerodus, the sabre-toothed Tiger, reduced.

India.—Not less important than the massive Pliocene accumulations of the Mediterranean basin, are those which have been found in Sind, the Punjab, and other north-western tracts of India. In Sind, the noteworthy fact has been made out by the Indian Geological Survey that, from the Upper Cretaceous to the Pliocene beds, the whole succession of strata, with some local exceptions, is conformable and continuous; yet contains

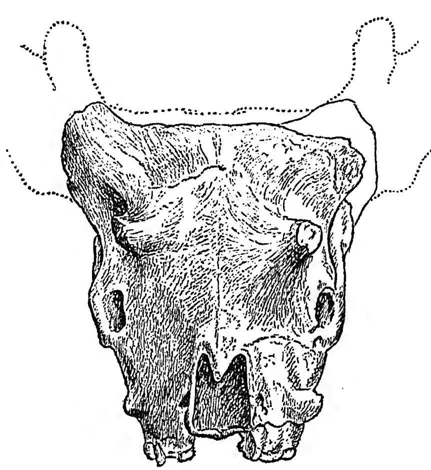

Fig. 489.—Sivatherium giganteum, Falc, reduced.
A gigantic ungulate allied to the giraffes and antelopes, having two pairs of horns; Siwalik beds of India.

[1] *Compt. rend.* 31st Dec. 1888; 1891, pp. 608, 708.

evidence of alternations of marine and terrestrial conditions, the latest marine intercalations being of Miocene date. The upper division of the Manchhar group (p. 1272) is not improbably referable to the Pliocene period. It consists of clays, sandstones, and conglomerate, 5000 feet thick, which have yielded some indeterminable fragmentary bones. Similar strata cover a vast area in the Punjab. They are admirably exposed in the long range of hills termed the Sub-Himalayas, which from the Brahmaputra to the Jhelum, a distance of 1500 miles, flank the main chain, and consist chiefly of soft massive sandstone, disposed in two parallel lines of ridge, having a steep southerly face and a more gentle northerly slope, and separated by a broad flat valley. These strata comprise what has been termed the Siwalik group—an accumulation of subaerial or fresh-water strata, the thickness of which has been estimated at 14,000 feet in the north-west Punjab, and at least 1500 feet in the Siwalik hills. Its component clays, sandstones, and conglomerates have been deposited by great rivers, which appear to have flowed from the Himalayan chain by the same outlets as their modern representatives. These deposits vary according to their position relatively to the great rivers. They have been involved in the last colossal movements whereby the Himalayas have been upheaved, yet their structure shows that the same distribution of the water-courses has been maintained as existed before the disturbance. In this instance, as in that of the Green River through the Uinta range in western America, the inference seems to be legitimate that the elevation of the mountains must have proceeded so slowly that the erosion by the rivers kept pace with it, and the positions of the valleys were therefore not sensibly changed (see p. 1375).

The Siwalik fauna includes a few mollusks, some, if not all, of which are identical with living species, such as the land-snail *Bulimus insularis*, a species which at the present day ranges from Africa to Burma, and the two common Indian river-snails *Viviparus bengalensis* and *V. dissimilis*, besides species of *Melania*, *Ampullaria*, and *Unio*. But the main part of the fauna consists of mammalia comprising 71 species that can be assigned to 39 living genera and 37 species belonging to 25 genera that are now extinct. The vertebrate part of this fauna, so far as known, is shown in the subjoined table, the existing genera being marked with an asterisk:[1]—

MAMMALIA.—Primates.—*Troglodytes*,* 1 sp.; *Simia*,* 1; *Semnopithecus*,* 1; *Macacus*,* 1; *Cynocephalus*,* 2.

Carnivora.—*Mustela*,* 1; *Mellivora*,* 2; *Mellivorodon*, 1; *Lutra*,* 3; *Hyænodon*, 1; *Ursus*,* 1; *Hyænarctos*, 3; *Canis*,* 2; *Amphicyon*, 1; *Viverra*,* 2; *Hyæna*,* 4; *Lepthyæna*, 1; *Hyænictis*, 1; *Æluropsis*, 1; *Ælurogale*, 1; *Felis*,* 5; *Machærodus*, 2.

Proboscidea.—*Elephas*,* 6 (*Euelephas*,* 1; *Loxodon*,* 1; *Stegodon*, 4); *Mastodon*, 5; *Dinotherium*, 1.

Ungulata.—*Chalicotherium*, 1; *Rhinoceros*,* 3; *Equus*,* 1; *Hipparion*, 2; *Hippopotamus*,* 1; *Tetraconodon*, 1; *Sus*,* 5; *Hippohyus*, 2; *Sanitherium*, 1; *Merycopotamus*, 3; *Cervus*,* 3; *Dorcatherium*, 2; *Tragulus*,* 1; *Moschus*,* 1; *Palæomeryx*, 1; *Camelopardalis*,* 1; *Helladotherium*, 1; *Hydaspitherium*, 2; *Sivatherium*, 1; *Alcelaphus*,* 1; *Gazella*,* 1; *Cobus*,* 2; *Antilope*,* 1; *Hippotragus*, 1; *Oreas** (?), 1; *Strepsiceros** (?), 1; *Boselaphus*, 1; *Palæoryx* (?), 1; *Probubalus*,* 2; *Leptobos*, 1; *Bison*,* 1; *Bos*, 3; *Bucapra*, 1; *Capra*,* 2; *Ovis*,* 1; *Camelus*,* 2.

Rodentia.—*Nesokia*,* 1; *Rhizomys*,* 1; *Hystrix*,* 1; *Lepus*,* 1.

AVES.—*Phalacrocorax*,* 1; *Leptoptilus*,* 1; *Pelecanus*,* 2; *Mergus*,* 1; *Struthio*,* 1.

REPTILIA.—Crocodilia.—*Crocodilus*,* 1; *Gavialis*,* 3; *Rhamphosuchus*, 1.

Lacertilia.—*Varanus*,* 1.

Chelonia.—*Colossochelys*, 1; *Bellia*,* 2; *Damonia*,* 1; *Kachuga*,* 3; *Hardella*,* 1; *Emyda*,* 4; *Trionyx*,* 1; *Chitra*, 1.

[1] Falconer and Cautley, 'Fauna Antiqua Sivalensis,' 1845-49. 'Geology of India,' p. 360. Blanford, *Brit. Assoc.* 1880, p. 577; Address, *Geol. Sect. Brit. Assoc.* 1884. Lydekker, 'Palæontologia Indica,' ser. x. vols. i. ii. iii.; *Records Geol. Surv. India*, 1883, p. 81; 'Cat. Sewalik Vert. Ind. Mus.' 1885-86, and Catalogues of British Museum.

PISCES.—*Carcharias*,* 1; *Ophiocephalus*,* 1; *Clarias*,* 1; *Heterobranchus*, 1; *Chrysichthys*, 1; *Macrones*,* 1; *Rita*,* 1; *Arius*,* 1; *Bagarius*,* 1.

In this list there is considerable resemblance to the grouping of mammalia in the Pikermi deposits, particularly in the preponderance of large animals, the absence or rarity of the smaller forms (rodents, bats, insectivores), and the marked Miocene aspect of certain parts of the fauna. Of the total assemblage of vertebrates found at Pikermi eighteen genera, or considerably more than half, have been also obtained from the Siwalik series, including the peculiar and characteristic *Helladotherium*. Mr. Blanford and his colleagues of the Geological Survey of India have shown that, though it has been classed as Miocene, the Siwalik fauna has such relations to Pliocene and recent forms as are found in no true Miocene fauna.[1] The large proportion of existing genera is the most striking feature of the assemblage. The preponderance of species belonging to such familiar genera as *Macacus*, *Ursus*, *Elephas*, *Equus*, *Hippopotamus*, *Bos*, *Hystrix*, *Mellivora*, *Meles*, *Capra*, *Camelus*, and *Rhizomys* give the whole assemblage a singularly modern aspect. It should be added that, of the six or seven determinable reptiles, three are now living in northern India; that of the birds, one is probably identical with the living ostrich, and that all the known land and fresh-water shells, with one possible exception, are of existing species.[2]

North America.—The existence of marine deposits referable to the Pliocene period has now been ascertained both on the Atlantic and Pacific borders of the United States. On the eastern side of the country they stretch from the Gulf of Mexico through the Carolinas, and in scattered patches as far as Virginia. They are best seen in Florida, which appears to have been still under water during Pliocene time. Hence they have been classed as the Floridian series, in which have been recognised (*a*) a lower group (Caloosahatchie, Waccamaw), and (*b*) an upper group, variously termed De Soto and Croatan. Higher still comes the Lafayette group, including the Lagrange beds, Orange sand, &c. Among the prevalent species of the Floridian series are *Ostrea meridionalis*, *Plicatula ramosa*, *Pecten irradians*, *Arca lienosa*, *Pectunculus undatus*, *P. pectinatus*, *Crassatella Gibbesii*, *Venus latilirata*, *Terebra dislocata*, *Conus Agassizii*, *Oliva literata*, *Nassa obsoleta*, *N. acuta*, *Crepidula fornicata*. In the Waccamaw or older part of the series the proportion of living species is about 70 per cent, while in the younger or Croatan beds the proportion is more than 85 per cent. On the Pacific coast, owing to the greater amount of uplift in the later part of the Tertiary period,[3] a more ample development of Pliocene deposits has been exposed, upwards of 5000 feet of strata of this age being visible in the San Francisco peninsula. This enormous thickness of sediment, unparalleled, so far as known, among strata of this age elsewhere in the New World, is visible on the sea-cliff (720 feet high) which extends for a few miles south of Lake Merced. The rocks, which have there been tilted generally at high angles in a monoclinal fold, consist chiefly of soft grey sandstones and sandy shales, with frequent hard shell beds and seams of pebbly conglomerate. These sediments were probably accumulated to so exceptional an extent as a kind of local or delta accumulation. At their base, which rests unconformably on Mesozoic rocks, lies a band of carbonised vegetation, with cones of

[1] Some doubt rests on the horizons from which many of the described Siwalik fossils were obtained. If the exact positions were ascertained, it would probably be found that there is less commingling of Miocene and Pliocene types than appears from the lists, and that the older types have really, to a greater or less extent, been derived from earlier parts of the formation than the younger types.

[2] Blanford, *Brit. Assoc.* 1880, p. 578, and 1884, Address.

[3] W. H. Dall. *Trans. Wagner Inst. Philadelphia*, iii. Part ii. (1892), p. 215.

[4] Pliocene fossils are reported to have been found in indurated material at heights of 2500 feet in the Monte Diablo range, and at 5000 feet near Mount St. Elias (*Bull. U. S. G. S.* No. 84, p. 271).

Pinus insignis, which is now found growing only at Monterey. Higher up, marine shells are abundant, a large proportion belonging to still living species, such as *Chione succinta*, *Arca schizotoma*, *Mytilus edulis*, *Venericardia ventricosa*, *Solen sicarius*, *Siliqua patula*, *Nassa fossata*, *N. mendica*, *Purpura crispata*, *Macoma nasuta*, *M. edulis*. A stratum full of tree-trunks lies about the middle of the series, but marine shells are found above it.[1] Farther south on the coast, at San Pedro, near Los Angeles, an important display of Pliocene strata, graduating upward into the Pleistocene series, has been recently studied by Messrs. Arnold. The Pliocene portion of the section appears to vary from 50 to 180 feet in thickness. It consists of brown argillaceous sandstones, containing *Thyasira* (*Cryptodon*) *bisecta*, *Pecten caurinus*, *P. hericeus*, *P. expansus*, *Lucina acutilineata*, *Panomya ampla*, *Natica clausa*, several species of *Trophon* and northern *Pleurotomidæ*—the whole fauna containing 12 per cent of extinct species, and presenting a general resemblance to that which is living now at a depth of 20 to 50 fathoms off the coast at San Pedro.[2] Marine Pliocene deposits appear to be but poorly represented north of California, until we reach Alaska, where their presence has been recognised.[3]

In the interior of the continent no corresponding marine formations are found, but the series of subaerial, lacustrine, and fluviatile deposits of the previous Tertiary periods is continued. Two horizons have been recognised among these deposits which are referred to the Pliocene period. What is regarded as the older group (Palo Duro or Goodnight beds) is found in Texas, lying unconformably on a part of the Loup Fork series (p. 1273). It contains a fauna which, except for the presence of *Equus*, corresponds with that of the later Loup Fork beds, which, as already stated, may perhaps be Pliocene. Among the scanty remains are those of a rhinoceros (*Aphelops*) and a number of horses (*Protohippus*, *Pliohippus*, *Equus*). Of later date are the lacustrine clays and sands (150 to 200 feet thick) of western Texas and part of Oklahama, known as the Blanco stage. These have yielded the carnivores *Canimartes*, *Borophagus*, and *Felis*; the edentate *Megalonyx*; the proboscidians *Dibelodon* and *Tetrabelodon*; three species of *Equus*; and the camel *Pliauchenia*.[4]

Australia.—In New South Wales, during what are supposed to correspond with the later Miocene, Pliocene, and Pleistocene periods, the land appears to have been gradually rising and to have been exposed to prolonged denudation and, in the Middle Pliocene period, to great volcanic activity. Hence successive fluviatile terraces were formed and eroded in the valleys, and were in many cases buried under great streams of lava. It is in these buried river-beds that the "deep-leads" lie, from which such large quantities of gold have been obtained. They have preserved with wonderful perfection remains of the flora and fauna of the period. Among the plants are large trunks, branches, and fruits of trees, and also ferns. With these are associated fresh-water shells, traces of beetles, and bones of a number of extinct marsupials, some of which were distinguished by their great size. One of the most abundant and remarkable of these creatures was the *Diprotodon*, which attained the bulk of a rhinoceros or hippopotamus. Another is the *Nototherium*, probably somewhat like a large tapir, of which three species have been named. An extinct gigantic kangaroo (*Macropus Titan*) had a skull twice as long as that of the largest living species. There were also wombats (*Phascolomys*), and a marsupial lion (*Thylacoleo*), with the marsupial hyæna (*Thylacinus*), and *Sarco-*

[1] A. C. Lawson, "The Post-Pliocene Diastrophism of the Coast of Southern California,' *Bull. Geol. Univ. California*, i. No. 4 (1893), p. 142. Other writers regard the upper part of the Merced series as probably Pleistocene (G. H. Ashley, *Proc. Californ. Acad. Sci.* v. (1895), p. 312).

[2] D. and R. Arnold, *Journ. Geol.* x. (1902), p. 117.

[3] W. H. Dall and G. D. Harris, *Bull. U.S. G. S.* No. 84 (1892), p. 232 and map.

[4] W. D. Matthew, *Bull. Amer. Mus. Nat. Hist.* xii. (1899), p. 75.

philus or "devil," which still live in Tasmania. To these may be added the *Dromornis* —a large bird represented now by the emu.[1]

In Victoria a younger Tertiary series overlies the older volcanic rocks referred to on p. 1274, and is likewise associated with newer volcanic ejections. It includes both marine and fluviatile deposits. The marine group, with species of *Trigonia*, *Haliotis*, *Cerithium*, *Waldheimia*, &c., is found up to heights of 1000 feet above sea-level. The fluviatile deposits, besides auriferous gravels, include also beds of lignite with abundant remains of terrestrial vegetation, and have yielded remains of *Diprotodon*, *Phascolomys*, *Thylacoleo*, *Macropus*, *Procoptodon*, *Dasyurus*, *Hypsiprimnus*, *Canis dingo*, &c. Vast sheets of basaltic and doleritic lavas have overspread the plains and filled up the Pliocene river-beds.[2]

In Queensland the presence of Tertiary rocks is inferred rather than proved. But from the similarity of the volcanic rocks of that colony to those of Victoria and New South Wales, it is believed that the older and newer volcanic groups which have been established are likewise of Tertiary age.[3]

New Zealand.—Deposits referable to the Pliocene division of the geological record play an important part in the geology and industrial development of New Zealand. According to Sir J. Hector, they belong to a time when the land was much more extensive than it now is, and when in the North Island volcanic action reached its greatest activity. They constitute the Wanganui system of Captain Hutton. From 70 to 90 per cent of their mollusca are of still living species. In addition to this large percentage, the formation may be recognised by *Trophon expansus*, *Pleurotoma wanganuiensis*, *Trochus conicus*, *Dentalium nanum*, *Meretrix assimilis*, *Ostrea corrugata*, *Trochocyathus quinarius*, *Flabellum rugulosum*. In the South Island the Pliocene strata are to a large extent unfossiliferous gravels, such as those of the Canterbury Plains and the Monteri Hills, in Nelson, which were derived from the mountainous interior. That considerable terrestrial disturbance took place during and subsequent to the deposit of the Pliocene series is shown by the disturbed and elevated positions of the beds in some places. Here and there the marine strata have been raised to a height of 300 feet (near Napier to more than 2000 feet) above the sea without disturbance of their horizontal position; but elsewhere they have been completely overturned. The economic importance of these deposits arises mainly from their yielding the richest supplies of alluvial gold.[4]

PART V. POST-TERTIARY OR QUATERNARY.

This portion of the Geological Record includes the various superficial deposits in which nearly all the mollusca are of still living species. It is usually subdivided into two series: (1) an older group of deposits in which many of the mammals are of extinct species, to this group the names Pleistocene, Post-Pliocene, and Diluvial have been given; and (2) a later series, wherein the mammals are all, or nearly all, of still living species, to which the names Recent, Alluvial, and Human have been assigned. These subdivisions, however, are confessedly very artificial, and it is often exceedingly difficult to draw any line between them. The names assigned to them also are not free from objection. The epithet

[1] C. S. Wilkinson, 'Notes on Geology of New South Wales,' Sydney, 1882.

[2] R. A. F. Murray, 'Geology of Victoria,' p. 113.

[3] These volcanic accumulations are extensive and of great interest. They have been described by Mr. R. L. Jack in the 'Geology and Palæontology of Queensland,' chap. xxxv.

[4] Hector, 'Handbook of New Zealand,' p. 26; Hutton, *Q. J. G. S.* 1885, p. 211.

"human," for example, is not strictly applicable only to the later series of deposits, for it is quite certain that man coexisted with the fauna of the Pleistocene series.

In Europe and North America a tolerably sharp demarcation can usually be made between the Pliocene formations and those now to be described. The Crag deposits of the south-east of England, as we have seen, show traces of a gradual lowering of the temperature during later Pliocene times, and the same fact is indicated by the Pliocene fauna and flora on the Continent even in the Mediterranean basin. This change of climate continued until at last thoroughly Arctic conditions prevailed, under which the oldest of the Post-Tertiary or Pleistocene deposits were accumulated in northern and central Europe, and in Canada and the northern part of the United States.

It is hardly possible to arrange the Post-Tertiary accumulations in a strict chronological order, because we have no means of deciding, in many cases, their relative antiquity, seeing that as a rule they occur in scattered areas, and not clearly superposed on each other. The order in which they are classified has often been determined by theoretical considerations, which are always subject to revision. In the glaciated regions of the northern hemisphere the various glacial deposits are grouped as the older division of the series under the name of Pleistocene. Above them lie younger accumulations, such as river-alluvia, peat-mosses, lake-bottoms, cave-deposits, blown-sand, raised lacustrine and marine terraces, which, merging insensibly into those of the present day, are termed Recent or Prehistoric.

Section i. Pleistocene or Glacial.

§ 1. General Characters.

Under the name of the Glacial Period or Ice Age, a remarkable geological episode in the history of the northern hemisphere is denoted.[1]

[1] No section of geological history now possesses a more voluminous literature than the Glacial Period, especially in Britain and North America. For general information the student may refer to Lyell's 'Antiquity of Man.' J. Geikie's 'Great Ice Age,' 'Prehistoric Europe,' Address to Geological Section of British Association, 1889, and paper in *Trans. Roy. Soc. Edin.* xxxvii. Part i. (1893), p. 127. J. Croll's 'Climate and Time,' 'Discussions on Climate and Cosmology.' Professor Bonney's 'Ice-Work, Past and Present,' p. 189. A. Penck, 'Vergletscherung der Deutschen Alpen,' 1882. A. Penck, E. Brückner, and L. du Pasquier, "Le Système Glaciaire des Alpes," *Bull. Soc. Sci. Nat.*, Neuchâtel, xxii. 1894. A. Penck and E. Brückner, 'Die Alpen im Eiszeitalter,' 1901, 1902 *seq.* J. Partsch, 'Die Gletscher der Vorzeit in den Karpathen, &c.,' 1882. A. Favre, 'Carte des Anciens Glaciers de la Suisse, &c.,' Geneva, 1884. A. Baltzer, 'Der diluviale Aargletscher,' Berne, 1896. A. Falsan and E. Chantre, 'Anciens Glaciers, &c., de la partie moyenne du Bassin du Rhône,' 1879, and for detailed descriptions, to the *Quart. Journ. Geol. Soc.; Geol. Mag.; Zeitsch. Deutsch. Geol. Ges.; Jahrb. Preuss. Geol. Landesanst.: Geol. Fören. Stockholm; Amer. Journ. Science; Annual Reports U.S. Geol. Surv.; Bull. Amer. Geol. Soc.; American Geologist;* and *Journ. Geol.* for the last twenty or thirty years. Some of these and other writings are cited on later pages. For the American literature see more particularly p. 1340, *seq.*

The gradual refrigeration of climate at the close of the Tertiary ages (p. 1278) affected the higher latitudes alike of the Old and the New World. Some of the northern parts both of Europe and of North America appear to have stood higher above sea-level than they do now. Evidence, indeed, has been brought forward in support of the view that in some regions the land must have been greatly more elevated and extensive during the maximum glaciation than it is now. Thus from the floor of the Atlantic around the coasts of Scandinavia, the Faroe and British Isles, dead littoral shells have been dredged up in depths of between 100 and 300 metres, and the conclusion has been drawn from them that the general level of the sea-bottom at the time when these mollusks lived was 100 to 300 metres higher than at present. Still more striking, however, is the inference deduced from the distribution of the dead shells of the so-called Yoldia-clay over the bottom of the North Atlantic. These shells now live in the high Arctic seas at depths of from 5 to 15 fathoms, but numerous dead specimens of them have been dredged from depths of from 500 to 1333 fathoms. It seems difficult to account for their presence by the drifting action of icebergs or of coast-ice, and the only other conclusion to which they point is that which Brögger, Nansen, and others have adopted, that they indicate a former exceedingly arctic time when the surface of the lithosphere in the north-western part of the European region, whether land or sea-floor, stood at a height of at least 2600 metres above that which it now presents.[1]

As the cold increased the whole of the north of Europe came eventually to be buried under ice, which, filling up the basins of the Baltic and North Sea, spread over the plains even as far south as close to the site of London, and in Silesia and Gallicia to the 50th parallel of latitude. Beyond the limits reached by the northern ice-sheet, the climate was so arctic that snow-fields and glaciers stretched even over the comparatively low hills of the Lyonnais and Beaujolais in the heart of France. The Alps were loaded with vast snow-fields, from which enormous glaciers descended into the plains on either side, overriding ranges of minor hills on their way. The Pyrenees were in like manner covered, while snow-fields and glaciers extended southwards for some distance over the Iberian peninsula. In North America also, Canada and the eastern States of the American Union, down to about the 40th parallel of north latitude, lay under the northern ice-sheet.

The effect of the movement of the ice was necessarily to remove the soils and superficial deposits of the land-surface. Hence, in the areas of country so affected, the ground having been scraped and smoothed, the glacial accumulations laid down upon it usually rest abruptly, and without any connection, on older rocks. Considerable local differences may be observed in the nature and succession of the different deposits of the

[1] See the evidence on this subject fully stated by Prof. Brogger in his 'Om de Senglaciale og Postglaciale Niväforandringer i Kristianiafeltet," *Norg. Geol. Undersög.*, No. 31 (1900 and 1901). Proofs of the former greater height of the land in western Europe and in eastern North America have long been recognised in the prolongation of fjords and land-valleys on the adjoining ocean-floor (*ante*, p. 391).

Glacial Period, as they are traced from district to district. It is hardly possible to determine, in some cases, whether certain portions of the series are coeval, or belong to different epochs. But the following leading facts have been established. First, there was a gradual increase of the cold, until the conditions of modern North Greenland extended as far south as Middlesex, Wales, the south-west of Ireland, and 50° N. lat. in Central Europe, and about 40° N. lat. in Eastern America. This was the culmination of the Ice Age,—the first or chief period of glaciation. Then followed an interval or interglacial period, during which the climate seems to have become much milder, though possibly with occasional returns of cold. This interlude was succeeded by another cold period, marked by a renewed augmentation of the snow-fields and glaciers,—a second period of glaciation.

It has been maintained by some observers that as many as four or five distinct epochs of cold are included within the geological interval represented by the Pleistocene deposits. Other writers contend for the essential unity of the Glacial Period. The truth will probably be found to lie somewhere between the extreme views. As shown in the sequel (p. 1312), demonstrable proof has been obtained of at least one interglacial period; and there may have been more than one advance of the northern ice into temperate latitudes. The interval or intervals of milder climate must have been of such prolonged duration that southern types of plant and animal life were enabled to spread northward and resume their former habitats.[1] Eventually, however, and no doubt very gradually, after episodes of increase and diminution, the ice finally retired towards the north, and with it went the Arctic flora and fauna that had peopled the plains of Europe, Canada, and New England. The existing snow-fields and glaciers of the Pyrenees, the Alps, and Norway in Europe and of the Rocky Mountains in North America are remnants of the great ice-sheets of the glacial period, while the Arctic plants of the mountains, which survive also in scattered colonies on the lower grounds, are relics of the northern vegetation that once covered Europe from Norway to Spain.

The general succession of events has been the same throughout all the European region north of the Alps, likewise in Canada, Labrador, and the north-eastern States, though of course with local modifications. The following summary embodies the main facts in the history of the Ice Age. Some local details are given in subsequent pages.

Pre-glacial Land-Surfaces.—Here and there, fragments of the land over which the ice-sheets of the Glacial Period settled have escaped the general extensive ice-abrasion of that ancient terrestrial surface, and have even retained relics of the forest growth that covered them. One of the best-known deposits in which these relics have been preserved is the so-called "Forest-bed group" (p. 1286). Above that deposit, as already described, there is seen, here and there, on the Norfolk coast, a local or

[1] Those who wish to enter into this debated subject will find it discussed from opposite sides in some recent papers by T. C. Chamberlin and G. F. Wright in the *Amer. Journ. Sci.* (1892, 1893), with references to other authorities.

intermittent bed of clay containing remains of Arctic plants (*Salix polaris*, *Betula nana*, &c., Fig. 490), together with the little marmot-like rodent, known as the souslik (*Spermophilus*). These relics of a terrestrial vegetation are drifted specimens, but they cannot have travelled far, and they probably represent a portion of the Arctic flora which had already found its way into the middle of England before the advent of the ice-sheet. Judging from the present distribution of the same plants, we may infer that the climate had become 20° Fahr. colder than it was during the time represented by the Forest bed—a difference as great as that between Norfolk and the North Cape at the present day.[1]

The Northern Ice-sheets.—At the base of the glacial deposits the solid rocks over the whole of Northern Europe and America present the characteristic smoothed flowing outlines produced by the grinding action of land-ice (p. 550). The rock-surfaces that look away from the

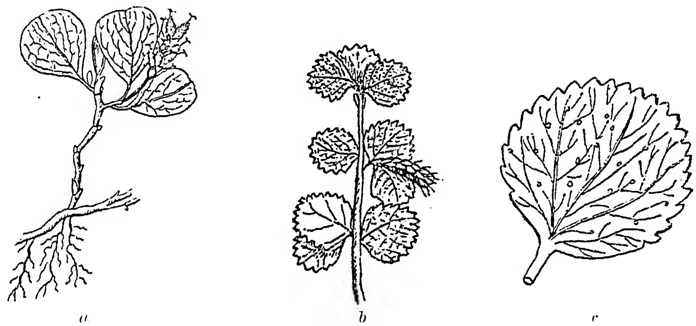

Fig. 490.—Arctic Plants found in Glacial Deposits.
a, Salix polaris, Wahlenb. (⅔); *b*, Betula nana, Linn.; *c*, Leaf of same, showing the size to which it grows in more southern countries.

quarter whence the ice moved are usually rough and weatherworn (Leeseite), while those that face in that direction (Stoss-seite) are all ice-worn. Even on a small boss of rock or on the side of a hill, it is commonly not difficult to tell which way the ice flowed, by noting towards which point the striæ run and the rough faces look. Long exposed, the peculiar ice-worn surface is apt to be effaced by the disintegrating action of the weather, though it retains its hold with extraordinary pertinacity. Along the fjords of Norway, the sea-lochs of the west of Scotland, and the headlands of Labrador it may be seen slipping into the water, smooth, bare, polished, and grooved, as if the ice had only recently retreated. Inland, where a protecting cover of clay or other superficial deposit has been newly removed, the peculiar ice-worn surface may be as fresh as that by the side of a modern glacier.

From the evidence of these striated rock-surfaces and the scattered blocks of rock that were transported to various distances, it has been

[1] C. Reid, *Horizontal Section, No.* 127 *of Geol. Survey*, and "Geology of the Country around Cromer" (sheet 68 E.), in *Memoirs of Geol. Survey*, 1882.

ascertained that the whole of Northern Europe, Canada, and the northern part of the United States was buried under one continuous mantle of ice. In Europe the southern edge of the ice-sheet must have lain to the south of Ireland, whence it passed along the line of the Bristol Channel, and thence across the south of England, keeping to the north of the valley of the Thames. The whole of the North Sea was filled with ice down to a line which ran somewhere between the coast of Essex and the present mouths of the Rhine, eastwards along the base of the Wesphalian hills, and round the projecting promontory of the Harz, whence it swung to the base of the Thuringerwald and struck eastwards across Saxony, keeping to the north of the Erz, Riesen, and Sudeten mountains; thence across Silesia, Poland, and Gallicia by way of Lemberg, and circling round through Russia by Kieff and Nijni Novgorod northwards by the head of the Dvina to the Arctic Ocean. The total area of Europe thus buried under ice has been computed to have been not less than 770,000 square miles.

Owing mainly to the direction of the prevalent moisture-bearing winds, the snowfall was greatest towards the west and north-west, and in that direction the ice-sheets attained their greatest thickness. Over Scandinavia, which was probably entirely buried beneath the icy covering, it was perhaps between 6000 and 7000 feet thick when at its maximum. Thence the sheet spread southwards, gradually diminishing in thickness. But from the striæ left by it on the Harz, it is computed to have been at least 1470 feet thick where it abutted on that ridge. The Scandinavian ice joined that which spread over Britain, where the dimensions of the sheet were likewise great. Many mountains in the Scottish Highlands show marks of the ice-sheet at heights of 3000 feet and more. If to this depth we add that of the deep lakes and fjords which were filled with ice, we see that the sheet may have been as much as 4000 or 5000 feet thick in the northern parts of Britain.

This vast icy covering, like the Arctic and Antarctic ice-sheets of the present day, was in continual motion, slowly draining downwards to lower levels. Towards the west, its edge reached the sea, as in Greenland now, and must have advanced some distance along the sea-floor until it broke off into bergs that floated away northward. Towards the south and east it ended off upon land, and no doubt discharged copious streams of glacier water over the ground in its front. In northern Germany, Denmark, Finland, and Scandinavia, the southern limits at which the ice rested a long while before retiring are indicated by long winding ramparts of detritus (Endmoräne). In North America also, the southern edge of the ice-sheet is marked by similar "terminal moraines," which are well displayed from Pennsylvania to Dakota.

The directions of movement of the ice-sheets can be followed by the evidence (1st) of striæ graven on the rocks over which the ice passed, and (2nd) of transported stones ("erratic blocks") which can be traced back to their original sources.

In Europe the great centre of dispersion for the ice-drainage was the table-land of Scandinavia. As shown by the rock-striæ in Sweden and

Norway, the ice moved off that area northwards and north-eastwards across northern Finland into the Arctic Ocean; westwards into the Atlantic Ocean, south-westwards into the basin of the North Sea; southward, south-westward, and south-eastward across Denmark and the low plains of Holland, Germany, and Russia, and the basins of the Baltic, Gulf of Bothnia, and Gulf of Finland. The evidence of the transported stones coincides with that of the striation, and is often available when the latter is absent.

United with the Scandinavian ice, but having an independent system of drainage, was the ice-sheet that covered nearly the whole of Britain. The rock-striæ show that while it probably buried the country even over its highest mountain-tops, it moved outward from each chief mass of high ground. Thus, from the Scottish Highlands, which were the main gathering ground, it drained northward to join the Norwegian ice, and move with it in a north-westerly direction across the Orkney and Shetland Islands. Westward it descended into the Atlantic; eastwards into the basin of the North Sea, to merge there also into the Scandinavian sheet and that which streamed off from the high grounds of the south of Scotland, and to move as one vast ice-field in a south-south-east direction across the north-east and east of England. Southwards it flowed into the basin of the Clyde and the Irish Sea, to unite with the streams moving from the south-west of Scotland and the north-west of England and Wales. The centre of Ireland appears also to have been an area from which the ice moved outwards, passing into the Atlantic on the one side and joining the British ice-fields on the other.

It is when we follow the direction of the ice striæ, and see how they cross important hill ranges, that we can best realise the massiveness of the ice-sheet and its resistless movement. As it slid off the Scottish Highlands, for instance, it went across the broad plains of Perthshire, filling them up to a depth of at least 2000 feet, and passing across the range of the Ochil Hills, which at a distance of twelve miles runs parallel with the Highlands, and reaches a height of 2352 feet. Mountains of 3000 feet and more, with lakes at their feet, 600 feet deep, have been well ice-worn from top to bottom. It has been observed that the striæ along the lower slopes of a hill-barrier run either parallel with the trend of the ground or slant up obliquely, while those on the summits may cross the ridge at right angles to its course, showing a differential movement in the great ice-sheet, the lower parts, as in a river, becoming embayed, and being forced to move in a direction sometimes even at a right angle to that of the general advance.. On the lower grounds, also, the striæ, converging from different sides, unite at last in one general trend as the various ice-sheets must have done when they descended from the high grounds on either side and coalesced into one common mass. This is well seen in the great central valley of Scotland. Still more marked is the deflection of the striæ in the basin of the Moray Firth. Northwards they are turned in a N.N.W. direction across Caithness and the Orkney Islands, pointing to the influence of the more gigantic Scandinavian ice-sheet. On the south side of the basin they

run E. by S., until in the north-east of Aberdeenshire they swing northward under the sea. The striæ that descend from the eastern and south-eastern Highlands bend round sharply to the N.N.E., as they approach the coast, with which they then run on the whole parallel, showing how the Scottish ice was pressed against the land by the large body which occupied the bed of the North Sea, and was here moving in a general northerly or north-westerly direction. To the south of the peninsula of Fife the striæ begin to bend towards S.E. and continue that course past the Cheviot Hills into England. The great mass of ice which crept down the basin of the Firth of Clyde was joined by that which descended from the uplands of Carrick and Galloway, and the united stream filled up the Irish Sea and passed over the north of Ireland. At that time England and the north-west of France were probably united, so that any portion of the North Sea basin not invaded by land-ice would form a lake, with its outlet by the hollow through which the Strait of Dover has since been opened.

When this glaciation took place the terrestrial surface of the northern hemisphere had acquired the main configuration which it presents to-day. The same ranges of hills and lines of valley which now serve to carry off the rainfall served then to direct the results of the snowfall seawards. The snow-sheds of the Ice Age probably corresponded essentially with the water-sheds of the present day. Yet there is evidence that the coincidence between them was not always exact. In some cases the snow and ice accumulated to so much greater a depth on one side of a ridge than on the other that the flow actually passed across the ridge, and detritus was carried out of one basin into another. A remarkable instance of this kind has been observed in the north of Scotland, where so thick was the ice-sheet that fragments of rock from the centre of Sutherland have been carried up westward across the main water-parting of the country and have been dropped on the western side.[1]

In North America, also, abundant evidence is afforded of a northern ice-sheet which overrode Canada and the eastern States, southwards to about the 40th parallel of latitude in the valley of the Missouri. Several centres of dispersion have been noted from which this ice moved outward, chiefly in a general southerly direction, but in the middle part the ice streamed northward into the Arctic Ocean. The great mountain ranges farther south likewise nourished numerous valley glaciers, which radiated outwards from the high ground. Some further details regarding the areas covered by the ice, and the traces of glaciation are given at pp. 1328-1346.

Beyond the limits of the northern ice-sheet, the European continent nourished snow-fields and glaciers wherever the ground was high enough and the snowfall heavy enough to furnish them. As already mentioned, the precipitation of moisture during the Ice Age, as at present, was greatest towards the west, and consequently in the western tracts the independent snow-fields and glaciers were most numerous and extensive. Even at the present time, the glaciers of the western part of the Alpine

[1] Peach and Horne, *Brit. Assoc.* 1892, p. 720.

chain are larger than those farther east. At the time of the northern ice-sheet a similar local difference existed. The present snow-fields and glaciers of these mountains, large though they are, form no more than the mere shrunken remnants of the great mantle of snow and ice which then overspread Switzerland. In the Bernese Oberland, for example, the valleys were filled to the brim with ice, which, moving northwards, crossed the great plain, and actually overrode a part of the Jura Mountains; for huge fragments of granite and other rocks from the central chain of the Alps are found high on the slopes of that range of heights. The Rhone glacier swept westward across all the intervening ridges and valleys, and left its moraine-heaps in the valley of the Rhone where Lyons now stands. At the same time the high grounds of the Lyonnais, Beaujolais, and Auvergne (lat. 45° S.) had their glaciers. Others flourished on the Iberian tableland, at least as far south as the basin of the Douro (lat. 41°). Eastwards in corresponding latitudes glacier relics become scantier and disappear. The Vosges possessed a group of glaciers which have left behind them some beautifully perfect moraines. Less extensive were those of the Black Forest, Sudetengebirge, and Carpathians. No trace of glaciation has been detected in the Balkans. A similar relation between snowfall and glaciation is traceable in North America, but there it is the eastern area which supported the massive ice-sheets, while the western plateaux and mountain-ranges, which were probably then, as now, comparatively arid, had only valley-glaciers.

That the ice in its march across the land striated even the hardest rocks by means of the sand and stones which it pressed against them, is a proof that, to some extent at least, the terrestrial surface must have been at this time abraded and lowered in level. How far this erosion proceeded, or, in other words, how much of the undoubtedly enormous denudation everywhere visible over the glaciated parts of the northern hemisphere, is attributable to the actual work of land-ice, is a problem which may never be satisfactorily solved. There seems good ground for the belief that a thick cover of rotted rock—the result of ages of previous sub-aerial waste—lay over the surface, and that the "glacial deposits" consist in great measure of this material, moved and reassorted by ice and water (pp. 458, 552). The land, as above remarked, had the same general features of mountain, valley, and plain as it has now, even before the ice settled down upon it. But the prominences of solid rock reached by the ice were rounded off and smoothed over, the pre-glacial soils with the covering of weathered material were in large measure ground up and pushed away, the valleys were correspondingly deepened and widened, and the plains were strewn with ice-borne débris. It is obvious that the influence of the moving ice-sheets has been far from uniform upon the rocks exposed to it, this variation arising from differences in the powers of resistance of the rocks, on the one hand, and in the mass, slope, and grinding power of the ice on the other. Over the lowlands, as in Central Scotland and much of the north German plain, the rocks are for the most part concealed under deep glacial débris. But in the more undulating hilly ground, particularly in the north and north-west, the

ice has effected the most extraordinary abrasion. It is hardly possible, indeed, to describe adequately in words these regions of most intense glaciation. The old gneiss of Norway and Sutherlandshire, for example, has been so eroded, smoothed, and polished that it stands up in endless rounded hummocks, many of them still smooth and curved like dolphins' backs, with little pools, tarns, and larger lakes lying in basins of the bare rock between them. Seen from a height the ground appears like a billowy sea of cold grey stone. The lakes, each occupying a hollow of erosion, seem scattered broadcast over the landscape. So enduring is the rock that, even after the lapse of so long an interval, it retains its ice-worn aspect almost as unimpaired as if the work of the glacier had been done only a few generations since.[1] The abundant smoothed and striated rock basin lakes of the northern parts of Europe and North America are a striking evidence of ice-action (pp. 552, 1386). The phenomenon of "giants' kettles," characteristic of many glaciated rock-surfaces (p. 551), is another mark of the same process of erosion.

Ice-crumpled and disrupted Rocks.—While the general surface of the land has been abraded by the ice-sheets, more yielding portions of the rocks have been broken off, bent back, or corrugated by the pressure of the advancing ice (pp. 548, 669). Huge blocks 300 yards or more in length have been bodily displaced and launched forward on glacial detritus. Such are some of the enormous masses of chalk displaced and imbedded in the drift of the Cromer cliffs, and the transported sheets of Lincolnshire Oolite found in Leicestershire.[2] The laminæ of shales or slates are observed to be pushed over or crumpled in the direction of ice movement. Occasionally tongues of the glacial detritus which was simultaneously being pressed forward under the ice have been intruded into cracks in the strata, so as to resemble veins of eruptive rock.[3]

Detritus of the Ice-sheet.—Underneath the great ice-sheet, and probably partly incorporated in the lower portions of the ice,[4] there accumulated a mass of earthy, sandy, and stony matter (till, boulder clay, "grundmoräne," "moraine-profonde," "older diluvium") which, pushed along and ground up, was the material wherewith the characteristic flowing outlines and smoothed, striated surfaces were produced.[5] This "glacial drift" spreads over the low grounds that

[1] Some of these *roches moutonnées* in N.W. Scotland may be of Palæozoic age, and the Torridonian breccias which cover them have a singularly "glacial" aspect (*Nature*, August 1880, and *ante*, p. 891).

[2] Mr. Fox Strangways has noticed one such sheet near Melton which measures at least 300 yards in length by 100 in breadth, but may extend beneath the boulder-clay to a greater distance. *Report of Geol. Surv. United Kingdom* for 1892, p. 249.

[3] On the disruption of the Chalk below the Till of Cromer see C. Reid on "Geology of Cromer," *Mem. Geol. Surv.* 1882. For analogous phenomena at Möens Klint, off the coast of Denmark, see Johnstrup, *Z. D. G. G.* xxvi. (1874), p. 533. Compare also H. Credner, *op. cit.* xxxii. (1880), p. 75. F. Wahnschaffe, *op. cit.* xxxiv. (1882), p. 562.

[4] Brueckner, *Penck's Geographische Abhandl.* Band I. Heft 1.

[5] As above suggested, the materials of the till, at least at the beginning, may have consisted largely of a layer of decomposed rock due to prolonged pre-glacial disintegration. The

were buried under the northern ice-sheets, resting usually on surfaces of rock that have been worn smooth, disrupted, or crumpled by ice. It is not spread out, however, as a uniform sheet, but varies greatly in thickness and in irregularity of surface. Especially round the mountainous centres of dispersion, it is apt to occur in long ridges ("drums," or "drumlins"), which run in the general direction of the rock striation, that is, in the path of the ice-movement. It may be traced up many valleys into the mountains, underlying the moraines of the later glaciation. In other valleys, it has been removed by the younger glaciers. In most glaciated countries the boulder-clay is not one continuous deposit, but may be separated into two or more distinct formations, which lie one on the other, and mark distinct and successive periods of time.

In those areas which served as independent centres of dispersion for the ice-sheet, boulder-clay partakes largely of the local character of the rocks of each district where it occurs. Thus in Scotland, the clay varies in colour and composition as it is traced from district to district. Over the Carboniferous rocks it is dark, over the Old Red Sandstones it is red, over the Silurian rocks it is fawn-coloured. The material of the deposit is generally an earthy or stony clay, which in the lower parts is often exceedingly compact and tenacious. The higher portions are frequently loose in texture, but alternations of hard tough clay and more friable material may be met with in the same deposit. In general, boulder-clay is unstratified, its materials being irregularly and tumultuously heaped together. But rude traces of bedding may not infrequently be detected, while in some cases, especially in the higher clays, distinct stratification or intercalated seams of sand or gravel may be observed.

The great majority of the stones in boulder-clay are of local origin, not always from the immediately adjacent rocks, but from points within a distance of a few miles.[1] Evidence of transport can be gathered from the stones, for they are found in almost every case to include a proportion of fragments which have come from a distance. The direction of transport indicated by the percentage of travelled stones agrees with the traces of ice-movement as shown by the rock striae. Thus, in the lower part of the valley of the Firth of Forth, while most of the fragments are from the surrounding Carboniferous rocks, from 5 to 20 per cent have come eastward from the Old Red Sandstone range of the Ochil Hills—a distance of 25 or 30 miles; while 2 to 5 per cent are pieces of the Highland rocks, which must have come from high grounds at least 50 miles to the north-west. The farther the stones in the till have travelled, the smaller they usually are. As each main mass of elevated

manner in which the glaciers of Spitzbergen and Greenland involve and press forward and upward the detritus beneath them, has been described at pp. 544-548. That the ice can override soft deposits without displacing them, has been noticed in Alaska, and a remarkable example of the occasional and sometimes extensive preservation of undisturbed loose pre-glacial deposits under the till is presented by the "Forest-bed" group, which has escaped for so wide a space under the Cromer cliffs, with their proofs of enormous ice-movement.

[1] See R. D. Salisbury, "The Local Origin of Glacial Drift," *Journ. Geol.* viii. (1900), p. 426. This general local origin is as marked in Canada and the United States as in Europe.

ground seems to have caused the ice to move outward from it for a certain distance, until the stream coalesced with that descending from some other height, the bottom-moraine or boulder-clay, as it was pushed along, would doubtless take up local débris by the way, the detritus of each district becoming more and more ground up and mixed, until of the stones from remoter regions only a few harder fragments might be left. In cases where no prominent ridges interrupted the march of the ice-sheet, and where the ground was low and covered with soft loose deposits, blocks of hard crystalline rocks might continue to be recognisable far from their source. Thus in the stony clay and gravel of the plains of Northern Germany and Holland, besides the abundant locally-derived detritus, fragments occur which have had an unquestionably northern origin. Some of the rocks of Scandinavia, Finland, and the Upper Baltic are of so distinctive a kind that they can be recognised in small pieces. The peculiar syenite of Laurwig, in the south of Norway, has been found abundantly in the drift of Denmark; it occurs also in that of Hamburg, and has been detected even in the boulder-clay of the Holderness cliffs in Yorkshire. The well-known rhombenporphyry of Southern Norway has likewise been recognised at Cromer, in Holderness, and around Cambridge. Fragments of the Silurian rocks from Gothland, or from the Russian islands Dago or Oesel, are scattered abundantly through the drift of the North German plain, and have been met with as far as the north of Holland. Pieces of granite, gneiss, various schists, porphyries, and other rocks, probably from the north of Europe, occur in the till of Norfolk.[1] These transported fragments are an impressive testimony to the movements of the northern ice. No Scandinavian blocks have been met with in Scotland, for the Scottish ice was massive enough to move out into the basin of the North Sea, until it met the northern ice-sheet streaming down from Scandinavia, which was thereby kept from reaching the more northerly parts of England.

The stones in boulder-clay have a characteristic form and surface. They are usually oblong, have one or more flat sides or "soles," are smoothed or polished, and have their edges worn round (Fig. 159). Where they consist of a fine-grained enduring rock, they are almost invariably striated, the striæ running on the whole with the long axis of the stone, though one set of scratches may be seen crossing and partially effacing another, which would necessarily happen as the stones shifted their position under the ice. These markings are precisely similar to those on the solid rocks underneath the boulder-clay, and have manifestly been produced in the same way by the mutual friction of rocks, stones, and grains of sand as the whole mass of débris was being steadily pushed on in one general direction.

As above remarked, boulder-clay is not always a single continuous

[1] These erratics, from their petrographical characters, appear to me to be certainly not from Scotland. Had that been their source they could not have failed to be accompanied by abundant fragments of the rocks of the south of Scotland, which are conspicuously absent. See V. Madsen, *Q. J. G. S.* xlix. (1893), p. 114.

deposit. On the contrary, when a sufficiently large extent of it is examined, evidence can commonly be found of two or more distinct divisions. These are separable from each other by differences of colour, composition, and texture, sometimes by an intercalated deposit of another kind. An attentive study of them shows that they have been formed successively under ice-sheets moving often from different directions and transporting different materials. Their limits of distribution also vary, the lower and older subdivisions extending farther south and spreading over a wider area than the upper.

It has occasionally happened that during the movements of the ice a series of boulders near each other and about the same general level in the boulder-clay have been all scored and striated in the same direction. Such "striated pavements" were first noticed in Scotland by Milne Home and Maclaren,[1] and afterwards by Hugh Miller and others. They probably indicate intervals during which the ice may have been stationary or even retreated, and after which it again advanced, ploughing its way through the overlying detritus down to the platform on which these boulders had been deposited.

The boulder-clay has been regarded as a characteristically unfossiliferous deposit. In maritime districts, indeed, it has long been known to contain broken marine shells, and as the harder fragments of these shells are often striated, the opinion has gained ground that their presence proves the ice-sheet to have crossed parts of the sea-bed and to have ploughed up the sea-floor. Further research in recent years, however, has shown that minute marine organisms are much more widely distributed in the deposit than had been believed. Foraminifera have been obtained from the clay from a wide region of Scotland at all heights up to 1061 feet above the sea. Similar microzoa have been obtained from the boulder-clays of the west of England, while in Canada they have been found in boulder-clay at heights of 1850 and 1900 feet near Victoria on the Saskatchewan river, far in the heart of the continent.[2] The question of the extent of the glacial submergence is discussed at p. 1317.

Interglacial beds.—That the deposition of boulder-clay was interrupted by milder intervals, when the ice, partially at least, retreated from the land and allowed trees and other vegetation to grow up to heights of 800 or 900 feet above the sea, was first proved for Britain by observations at Chapel Hall, Lanarkshire.[3] During the forty years which have intervened since these observations were published, a large

[1] D. Milne Home, *Trans. R. S. Edin.* xiv. (1838), p. 310; C. Maclaren, 'Geology of Fife and the Lothians,' 1839; Hugh Miller, 'Geology of Edinburgh and its Neighbourhood,' p. 35; Hugh Miller (son), *Proc. Roy. Phys. Soc. Edin.* vii. (1884), pp. 156-189. An instance from Wilson, New York, is described by Mr. G. K. Gilbert, *Journ. Geol.* vi. (1898) p. 771, who supposes that the boulders were pressed into their present positions by the later eroding ice-sheet.

[2] See, for Scotland, J. Wright, *Trans. Geol. Soc. Glasgow*, 1894, pp. 263, 270; J. Smith, *Brit. Assoc.* 1896. For west of England, T. M. Reade, *Geol. Mag.* 1892, p. 310; 1896, p. 542; *Proc. Liverpool Geol. Soc.* 1893, p. 36; 1899, p. 350; *Q. J. G. S.* liii. (1897), p. 341. For Canada, G. M. Dawson, *Journ. Geol.* 1897, p. 257.

[3] A. G. *Trans. Geol. Soc. Glasgow*, vol. i. Part ii. (1863).

amount of additional information on this subject has been collected in the British Islands, on the continent of Europe, and in North America. The boulder-clays are now well known to be split up with inconstant and local stratifications of sand, gravel, and clay, often well stratified, pointing to conditions quite distinct from those under which ordinary boulder-clay was accumulated. These intercalations have been recognised as bearing witness to intervals when the ice retired and when ordinary water-action came into play over the ground-moraine thus exposed. Much controversy, however, has arisen as to the chronological value to be assigned to these intervals. To some geologists the intercalations in the boulder-clay appear to indicate little more than seasonal variations in the limits and thickness of the ice-sheets, such as now affect the glaciers of Scandinavia and the Alps. To others, again, they furnish proof of successive interglacial periods by which the long Ice Age was broken up. Thus Professor James Geikie, recently reviewing the whole evidence on the subject, has come to the conclusion that there were really in Europe six glacial intervals embraced within what is called the Glacial Period, separated from each other by five interglacial periods of mild temperature. These he arranges and names as in the subjoined table :[1]—

11. Upper Turbarian or 6th Glacial Epoch, indicated by the deposits of peat which underlie the lower raised beaches.

10. Upper Forestian or 5th Interglacial Epoch, shown by a buried forest, with a fauna and flora indicative of a temperate and dry climate.

9. Lower Turbarian or 5th Glacial Epoch, represented by certain peat deposits overlying the lower Forest-bed, by the Carse-clays and raised beaches of Scotland, and in part by the *Littorina*-clays of Scandinavia.

8. Lower Forestian or 4th Interglacial Epoch, embracing the great fresh-water lake of the Baltic area (*Ancylus*-beds), the lower forests under peat bogs, and the *Littorina*-clays of Scandinavia in part.

7. Mecklenburgian or 4th Glacial Epoch, especially displayed in the ground-moraines and terminal moraines of the last great Baltic glacier, which reach their southern limit in Mecklenburg; to the same stage are assigned the *Yoldia*-beds of Scandinavia and the 100 feet terrace of Scotland.

6. Neudeckian or 3rd Interglacial Epoch, represented by marine and fresh-water deposits between the boulder-clays of the southern Baltic coast-lands.

5. Polandian or 3rd Glacial Epoch, represented by the glacial and fluvio-glacial accumulations of the minor Scandinavian ice-sheet, and the "Upper boulder-clay" of northern and western Europe.

4. Helvetian or 2nd Interglacial Epoch, represented by the lignites of Switzerland, the interglacial beds of Britain, &c.

3. Saxonian or 2nd Glacial Epoch, including the accumulations of the period of maximum glaciation, when the northern ice-sheet extended to the low grounds of Saxony, and the Alpine glaciers formed the moraines of the outer zone.

2. Norfolkian or 1st Interglacial Epoch, typically represented by the Forest-bed group of Norfolk.

1. Scanian or 1st Glacial Epoch, represented only in the south of Sweden (Scania), which was overridden by a large Baltic glacier. To this period may belong the

[1] *Journ. Geol.* iii. (1895), p. 241. This classification is here given as an illustration of the more detailed schemes of subdivision which have been proposed. But its applicability to the north of Europe has been called in question. Professor Keilhack and his colleagues on the Prussian Geological Survey are of opinion that the ground-moraine called the Upper boulder-clay has no proof of belonging to more than a single ice-epoch (*op. cit.* v. (1897), p. 118), while N. O. Holst maintains that there has been only one glacial period in Sweden (*Sverig. Geol. Undersökning*, Ser. C. No. 151, 1895; translated into German by Dr. W. Wolff, Berlin, J. Springer, 1899).

Chillesford Clay and Weybourn Crag of Norfolk, and the oldest terminal moraines and fluvio-glacial gravels of the Arctic lands. [1]

Much difficulty in forming definite conclusions as to the importance of these obvious interruptions in the deposition of the boulder-clay arises from the absence of continuous sections wherein the order of succession of the several stages of the glacial history can be demonstrated by visible relations of superposition. A section at one locality has to be correlated with another at a greater or less distance, and assumptions have to be made as to the identity or difference of the various deposits. The evidence of fossils can hardly be said to be available, for it is so fragmentary as to have given hitherto little aid in determining the chronology of the deposits in which it occurs. The most successful effort to utilise the marine shells of the late glacial and post-glacial deposits for purposes of stratigraphical subdivision and correlation is that of Prof. Brögger in the Christiania district.[2]

The existence of two distinct deposits of boulder-clay, which has been found to be so widely recognisable, with an intervening group of sands, gravels, clays, and peat-beds, may be taken to afford good proof of two advances and retreats of the ice-sheets, with an interval of milder climatal conditions between them. The lower boulder-clay probably marks the greatest extent of the ice. The upper boulder-clay shows that though the ice on returning attained huge dimensions and formed continuous ice sheets over much of Northern Europe, it did not descend as far as at first. Yet while these two main epochs of maximum cold appear to be satisfactorily established, there seems no reason to doubt that each of them may have included minor fluctuations in temperature or in snowfall, so that the ice-sheets may have alternately or intermittently advanced and retreated over considerable tracts of country. The ground-moraine, when thus laid bare, may have been reassorted by water, arising from the melting of the ice or of snow, so that as the ice once more moved forward, it here and there pushed its detritus over the aqueous deposits of the milder interval. But the contrast between the lower and upper boulder-clay in composition and extent shows that the interval which separated them was probably of prolonged duration. That there is here evidence of at least one important interglacial period is generally, though not universally, admitted. But many able observers do not consider that the evidence at present known warrants us to advance further, and they refuse to recognise the multiplication of such periods as has been proposed. It certainly seems safer, when the scattered state and uncertainty of the correlation of the deposits are considered, to suspend judgment on this subject and to

[1] Professor Chamberlin has proposed an analogous classification of the glacial deposits of the United States, recognising an alternation of glacial and interglacial epochs, *Journ. Geol.* iii. p. 270. The attention of the student should be directed to the risk of error from the tendency of superficial glacial deposits to slip, and thus to overlie more recent deposits, and produce a deceptive appearance of interglacial alternations. Mr. Clement Reid has pointed out that some supposed interglacial peat-beds contain the seeds of introduced and cultured plants, and cannot therefore, as now exposed, be of the age claimed for them, *Geol. Mag.* 1895, p. 217.

[2] Cited on p. 1302.

be content with the recognition meanwhile of one great interglacial period. The best evidence for such a period is supplied by layers of sand, gravel, or stratified clay intercalated in the boulder-clay or moraine deposits, and accompanied with beds of peat or lignite, and an association of the remains of terrestrial plants and animals, sometimes with fresh-water shells. Such intercalations are widely distributed between the lower and upper boulder-clays of Britain, and in the older moraine series of Switzerland. Obviously, however, deposits of the same age may survive outside the glaciated regions, though there may be no very reliable means of establishing their correlation. Thus the older alluvial terraces of the south of England and north-west of France, with their remains of extinct mammals and human implements, have been regarded as equivalents of some of the interglacial deposits.

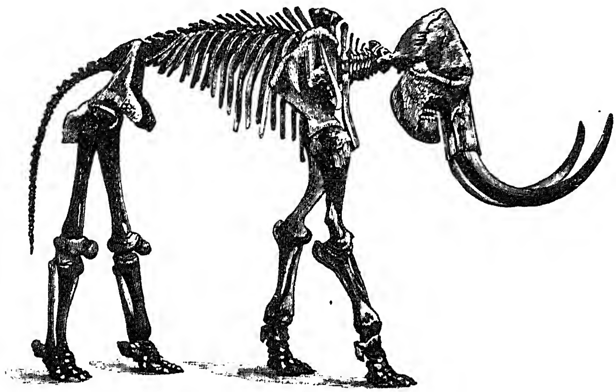

Fig. 491.—Mammoth (*Elephas primigenius*)
From the skeleton in the Musée Royal, Brussels (much reduced).

Flora and Fauna of the Glacial Period.—As great oscillations of climate took place during the Ice Age and in some cases probably lasted for a long time, the plants and animals both of land and sea could hardly fail to be seriously affected. During the cold intervals northern forms would probably migrate southwards, and in the warmer episodes southern forms would push their way northward. Among the distinctively Arctic or northern plants may be cited *Salix polaris*, *S. reticulata*, *Betula nana*, *Dryas octopetala*, and numerous mosses, such as *Bryum lacustre* and *Hypnum callichroum*. The Arctic terrestrial animals include the mammoth (Fig. 491), woolly rhinoceros, musk-sheep (Fig. 492), reindeer (Fig. 496), Arctic fox, and lemming.

The marine invertebrate fauna shared, though in a less degree, in the effects of the meteorological and geographical changes. During the times of great cold northern species found their way southwards, some of them even as far as the basin of the Mediterranean. Mollusks and foraminifera, now only living in high Arctic seas, then flourished abundantly over the submerged south of Norway, such as *Pecten islandicus*, *Portlandia* (*Yoldia*)

arctica, Nuculana (Leda) pernula, Tellina (Macoma) calcarea (=lata), Saxicava arctica, Polystomella arctica. Among the immigrants into Britain were *Pecten islandicus, Tellina (Macoma) calcarea, Portlandia (Yoldia) arctica,* and a number of others (Fig. 494). These flourished while the cold lasted, but were eventually killed off as the temperature rose, and are now restricted to Arctic waters.[1] The marine vertebrate fauna was characterised by the presence of species which have long retreated to the far north, such as the Arctic seals, whales, morse, and others. Thus from the higher raised beaches and glacial brick clays of Scotland the remains of the Arctic floe-rat (*Phoca hispida*) have been obtained at a number of places.[2]

During interglacial conditions the climate in the northern parts of our hemisphere was probably more equable and mild than at present, with a higher mean temperature and at certain intervals a greater precipitation of moisture.[3] From the general aspect of the flora and fauna preserved in interglacial deposits in Britain it may perhaps be inferred that there was then more sunshine than now. Mr. Reid has suggested that the scarcity of thoroughly aquatic mollusks and of fish indicates that during some stages, at least, the climate, while colder than at present, was dry rather than moist.[4] As a result of more favourable meteorological conditions vegetation flourished even far north where it can now hardly exist. The frozen tundras of Siberia appear then to have supported forests which have long since been extirpated, the present northern limit of living trees lying far to the southward. Indications of a more equable and milder climate are likewise supplied by the plant-remains found in Pleistocene tufas of different parts of Europe, where species now restricted to more southern countries were then able to flourish, together with those which are still native there.[5]

The interglacial terrestrial fauna was marked more especially by the presence of the last of the huge pachyderms, which had for so many ages been the lords of the European forests and pastures. The mammoth and rhinoceros, which then roamed over the plains of Siberia and across most, if not the whole, of Europe, were probably driven southward by the increasing cold. They appear, however, to have survived some of the advances of the ice, returning into their former haunts when a less wintry climate allowed the vegetation on which they browsed once more to overspread the land.[6] Some of the mammals now restricted to the far north likewise

[1] Valuable lists of the mollusks of the Glacial Period are given by Brogger in the memoir cited on p. 1302. An ample catalogue of the foraminifera has been prepared by V. Madsen, 'Meddelelser fra Dansk Geolog. Forening,' No. 2, 1895.

[2] Sir W. Turner, *Journ. Anat. Physiol.* iv. (1878), p. 260.

[3] J. Croll, *Phil. Mag.* 1885, p. 36.

[4] He has discussed the bearing of past floras and faunas as a whole upon the evolution of climate, *Natural Science* i. (1892), p. 427 ; iii. (1893), p. 367.

[5] Nathorst, *Engler's Botanische Jahrb.* 1881, p. 431 ; C. Schröter, 'Die Flora der Eiszeit,' Zürich, 1883.

[6] The mammoth lived in the neighbourhood of the extinct volcanoes of Central Italy, which were then in full activity. From discoveries in Finland, it has been inferred that the extinction of this animal may not have been much before historical times. A. J. Malmgren, *Oefv. Finsk. Vet. Soc. Forh.* xvii. p. 139. Consult Boyd Dawkins on the range

found their way into countries from which they have long disappeared. The reindeer migrated southwards into Switzerland,[1] the glutton into Auvergne, while the musk-sheep and Arctic fox travelled certainly as far as the Pyrenees. As the climate became less chilly, animals of a more southern type advanced into Europe: the porcupine, leopard, African lynx, lion, striped and spotted hyænas, African elephant, and hippopotamus.

In the non-glaciated regions various deposits containing remains of land animals and plants have been tentatively correlated with different parts of the glacial series, but such comparisons have often only a slender basis on which to rest. Such is the calcareous sandy clay which covers the surface of the great plains between South Dakota and Texas and which has been named the Sheridan Stage (Equus beds) from its development in Sheridan County, Nebraska. In that State, a remarkable assemblage of mammalian remains has been obtained near Hay Springs comprising horses, camels, a variety of the mammoth and a sloth, together with the remains of prairie dogs, gophers, field mice, and musk-rats—forms still living on the neighbouring plains.[2]

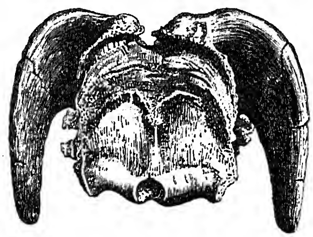

Fig. 492.—Back view of skull of Musk-sheep (*Ovibos moschatus*, ¼), Brick-earth, Crayford, Kent.

Evidences of Submergence.[3]—Reference has been made in the foregoing pages to the probability that at the time of maximum glaciation the land in northern Europe and America stood at a higher level than it does now, and to proofs of subsequent submergence. The presence of marine shells and foraminifera in the boulder-clay has been held by some observers to indicate the marine origin of the clay in which they lie, and thus to demonstrate the former submergence of the land at least below the upper limit at which they have been found. By other geologists these organisms in the boulder-clay are believed to have been pushed out of the sea floor by the ice-sheets and carried up over the land. Obviously the natural interpretation of the occurrence of marine organisms is that the deposit containing them has been laid down on the sea-bottom, from which it has subsequently emerged as land. There are conditions, however, in which the materials of the sea-bed may conceivably be spread over the land without any oscillation of the lithosphere. We have seen that in the great Greenland glaciers there is a

of the mammoth in space and time, *Q. J. G. S.* xxxv. (1879), p. 138; and Sir H. Howorth, *Geol. Mag.* 1880; 'The Mammoth and the Flood' and 'The Glacial Nightmare.'

[1] On the distribution of the reindeer at present and in older time, see C. Struckmann, *Zeitsch. Deutsch. Geol. Ges.* xxxii. (1880), p. 728.

[2] W. D. Matthew, *Bull. Amer. Mus. Nat. Hist.* xvi. (1902), p. 317.

[3] See Prestwich, *Phil. Trans.* vol. clxxxiv. (1893), A. pp. 903-984; *Q. J. G. S.* xlviii. (1892), pp. 263-343. D. Bell, *Trans. Geol. Soc. Glasgow*, 1889, p. 100; 1892, p. 321. T. Mellard Reade, *Geol. Mag.* 1892, p. 310; 1893, p. 19; 1896, p. 542; *Natural Science*, December 1893, and papers cited on later pages.

marked transport of detritus from the bottom to the surface of the ice. Where a thick ice-sheet crosses a shallow sea this kind of transport may still continue and may result in the enclosure and removal of more or less mud, sand, stones, and shells from the bottom of the sea.[1] As the ice is pushed out of the marine basin by the pressure of the mass behind the marine detritus may be carried up upon the land. Those who adopt this explanation of the marine organisms in the boulder clay point in support of their views to the universally broken and even comminuted condition of the shells and their frequent striation, to the constant separation of the valves of the lamellibranchs, to the absence of deep-water forms which must surely have been living in the adjoining seas, and to the remarkable commingling of living shallow-water species with others that have long been extinct.[2] It must be admitted that during the Glacial Period ice-sheets filled and crossed the sounds and more or less enclosed seas of the northern hemisphere. How high they may have been pushed out of the sea-bottom upon the land would depend on their mass and the *vis a tergo* that impelled them. Whether they could climb as far as the altitudes at which marine shells have been found is a question for the satisfactory solution of which our present information regarding the physics of great ice-sheets is insufficient.

As already stated, there is good reason to think that at the height of the glaciation or some time before it, much of Northern Europe and North America stood at a higher level than it has since reached. While ice still abounded on its surface the land was gradually submerged. The ice-fields were carried down below the sea level, where they broke up and cumbered the sea with floating bergs. The heaps of loose débris which had gathered under the ice, being now exposed to waves, ground-swell, and marine currents, were thereby more or less washed down and reassorted. Coast-ice, no doubt, still formed along the shores, and was broken up into moving floes, as happens every year now in Northern Greenland. The proofs of this phase of the long Glacial Period are contained in shell-bearing sands, gravels, and clays overlying the coarse older till, and are perhaps, to some extent, furnished by erratic blocks.[3] It is difficult to determine the

[1] Masses of submarine clay, as has been suggested by various observers, may conceivably be ploughed out of the sea-bottom and be transported for a long distance without the crushing of all their enclosed organisms.

[2] P. F. Kendall, *Geol. Mag.* 1892, p. 491.

[3] For a study of the late glacial and post-glacial deposits which chronicle the successive phases of the submergence, see the memoir of Prof. Brogger, already cited, where the subject is worked out in great detail in reference to the region of Southern Norway. For an account of the dispersion of "erratics," as illustrated by those of England and Wales, see Mackintosh, *Q. J. G. S.* xxxv. (1879), p. 425; and Reports of the Committee appointed to investigate this subject by the British Association, 1872-95; since which latter year the reconstituted Committee has included Scotland. For those of Scotland much information has been gathered by the Boulder Committee of the Royal Society of Edinburgh: *Proc. Roy. Soc. Edin.* 1872 and subsequent years. Erratic blocks have probably in the vast majority of cases been dispersed by land-ice, and not by floating ice.

extent of the submergence, and no part of the chronicles of the Ice Age has given rise to more discussion. Those who hold that the mere presence of marine organisms is enough to prove submergence, maintain that as sea-shells are found in North Wales and in Cheshire at heights varying up to 1200 and even 1350 feet, the country must have been under the sea at least up to these altitudes. Those of an opposite opinion, however, urge that in such circumstances it might have been expected that there would have been other, clearer and more wide-spread evidence of so extensive a general submergence. They therefore look upon the marine organisms as having been ploughed out of the sea-floor by the ice-sheet. This view might be accepted as a reasonable explanation for the phenomena displayed on low plains and maritime tracts. But it is difficult to understand how the ice could climb out of such a basin as that of the Irish Sea, and ascend such steep slopes as those of the Welsh hills up to a height of at least 1350 feet, or how the great northern ice-sheet of Canada could advance from the Arctic Ocean and carry up marine organisms to a height of 1900 feet in the valley of the Saskatchewan.

If the inference be accepted to which the evidence of the submerged shell-banks and dead littoral Arctic shells on the bed of the North Atlantic appears to point, a stupendous subsidence of the lithosphere in the northern part of our hemisphere must have occurred since the time of maximum glaciation. The submergence indicated by marine shells *in situ* on the land would, on this view, represent only the last part of a period of sinking. And if the submarine evidence requires a subsidence of perhaps as much as 6000 or 8000 feet, there may be little reason to dispute regarding the few hundred feet of difference between the limits of submergence adopted by the antagonists above referred to. If we confine ourselves to the testimony of marine organisms which lie in the positions wherein they lived and died, we obtain a criterion which all geologists will accept. Such a criterion is furnished by stratified clays and other sediments which represent sea-bottoms. Deposits of this character have been recognised over wide districts of northern Europe and Canada. Thus clays, sands, and gravels containing an Arctic fauna are abundant all round the coast of Scotland at a height of 100 feet. Some deposits wherein the northern shells are evidently *in situ* as they lived and died, are found up to heights of about 500 feet. There seems therefore no reason to doubt that the submergence reached as far as that limit; how much farther it went must remain for the present undetermined. From the same kind of evidence, southern Scandinavia is believed to have been submerged to a depth of from 600 to nearly 800 feet. Prof. Brögger has proposed the term "Christiania period" to denote the time of submergence, which not improbably coincides with the "Champlain period" of American glacialists.[1]

The cause of submergence has been variously explained. Some writers have supposed that the attraction of the vast masses of ice in the northern hemisphere caused a rise of the sea-level in these regions (p. 378).

[1] *Op. cit.* p. 205.

Others have suggested that the load of ice was enough to press down the underlying part of the terrestrial crust, which on the disappearance of the Arctic conditions would rise again.[1] A third view regards the movement as one of the lithosphere itself. For reasons already assigned I regard the last interpretation as most probable, though the influence of the ice may possibly have to some slight extent contributed. The instability of the surface of the lithosphere during Pleistocene time is shown by the fact that some part of the submerged ground was again raised into dry land before the end of the Glacial Period. We know, too, that in post-glacial time some of the Arctic lands have been undergoing an uplift, and that the rate of elevation varies horizontally.[2]

When the land once more emerged from the sea its higher grounds continued to be the seat of glaciers, which, moving over the surface, no doubt more or less destroyed the deposits that would otherwise have remained as witnesses of the presence of the sea, while at the same time the great bodies of water discharged from the retreating glaciers and snow-fields must have done much to reassort the detritus on the surface of the land. That ice continued to float about in the seas of northern and north-western Europe is shown by the striated stones contained in the fine clays, and by the remarkably contorted structure which these clays occasionally display. Sections may be seen (as at Cromer) where, upon perfectly undisturbed horizontal strata of clay and sand, other similar strata have been violently crumpled, while horizontal beds lie directly upon them. These contortions may have been produced by the horizontal pressure of some heavy body moving upon the originally flat beds, such as ice in the form of an ice-sheet or of large stranding masses driven aground in the fjords or shallow waters where the clays accumulated; or possibly, in some cases, sheets of ice, laden with stones and earth, sank and were covered up with sand and clay, which, on the subsequent melting of the ice, would subside irregularly. Another indication of the presence of floating ice is furnished by large scattered boulders, lying on the stratified sands and gravels. Though these blocks probably belong as a rule to the time of the chief glaciation, they may in some cases have been shifted about by floating ice during the submergence.

Second Glaciation—Reelevation—Raised Beaches.—When the land re-emerged, the temperature all over central and northern Europe was again severe. The northern ice-sheet once more advanced southwards, but did not again attain nearly the same dimensions. From the direction of the striæ, it would appear sometimes to have moved differently from its previous course, occasionally even at right angles to it. In the basin of the Baltic, for example, the later direction of the ice-stream appears to have been south-westwards and westwards. Besides the evidence of this direction furnished by striated rock surfaces,

[1] This view has been especially advocated by the able Swedish glacialist Baron G. de Geer, *Bull. Geol. Soc. Amer.* iii. (1892); *Proc. Boston Soc. Nat. Hist.* xxv. (1892), see also *postea*, p. 1326.

[2] Messrs. Garwood and Gregory, *Q. J. G. S.* liv. (1898), p. 219. Recent oscillations of the surface of the lithosphere are referred to on pp. 318-387, 1329, 1333, 1344, 1346.

abundant fragments of the fossiliferous Silurian rocks of Gothland are strewn over the Germanic plan even as far as Holland. There seems no reason to doubt that during this second advance of the ice the Scottish and Scandinavian ice-sheets were again united over what is now the floor of the North Sea. It was then that the upper boulder-clay of Britain was formed. The glaciers of the Alps once more marched outwards over the lower grounds, but without descending so far as before. Their limits are marked by an inner group of moraines.

From its second maximum the ice-sheet gradually shrank backward, though probably not without occasional pauses and even advances. As it retreated from the lower grounds it lost the aspect of a continuous ice-sheet, and when it reached the bases of the mountains it eventually separated into valley-glaciers radiating from each principal mass of high ground. In this condition also there was probably a long period of oscillation, the glaciers alternately descending and shrinking backward, as they still continue to do, with variations in the seasons. In Britain there is abundant evidence of this stage in the history of the Ice Age. The Scottish Highlands, being the largest area of high ground in the country, was the chief seat of the ice. Not only did every group of mountains nourish its own glaciers; even small islands, such as Arran and Hoy, had their snow-fields, whence glaciers crept down into the valleys and shed their moraines. It would appear indeed that some of the northern glaciers continued to reach the sea-level even when the land had there risen to near or quite its present elevation. On the east side of Sutherlandshire, at Brora, and on the west side of Ross-shire, at Loch Torridon, the moraines descend to the 50-feet raised beach; at the head of Loch Eriboll, they come down to the sea-level and even extend underneath the water, showing that the glacier at the head of that fjord actually pushed its way into the sea, and no doubt calved its icebergs there.

Another proof of the magnitude of some of the ice-streams that filled the valleys of the Scottish Highlands during the later stages of the Glacial Period is supplied by the proofs that here and there among the loftier or broader snow-fields of the time they accumulated in front of lateral valleys, the drainage of which was in consequence ponded back and made to flow out in an opposite direction by the *col* at the head (p. 543). In these natural reservoirs, the level at which the water stood for a time was marked by a horizontal ledge or platform, due partly to erosion of the hillside, but chiefly to the arrest of the descending débris when it entered the water. The famous "Parallel Roads of Glen Roy" are familiar examples, but other instances on a gigantic scale have been found in the northern United States and Canada (p. 1343).

The gradual retreat of the glaciers towards their parent snow-fields is admirably revealed by their moraines, perched blocks, and *roches moutonnées*. The crescent-shaped moraine-mounds that lie one behind another may be followed up a glen, until they finally die out about the head, near what must have been the edge of the snow-field. The highest mounds, being the last to be thrown down, are often singularly fresh.

They frequently enclose small lakes or pools of water, which have not yet been filled up with detritus or vegetation, or flat peaty bottoms where the process of filling up has been completed. Huge blocks borne from the crags above them are strewn over these heaps, and similar erratics perched on ice-worn knolls on the sides of the valleys mark some of the former levels of the ice. In Britain, the Scottish Highlands, the southern uplands of Scotland, the hills of the Lake District and of North Wales present admirable examples of all these features.

On the continent of Europe also similar evidence remains of the gradual retreat of the ice. In many tracts of high ground glaciers no longer exist. In the Vosges, for example, they have long since vanished, but fresh moraines remain there as evidence of their former presence. The Alpine glaciers are the lineal descendants of those which filled up the valleys and buried the lowlands of Switzerland and the Lyonnais.

Before the retiring ice-sheet had shrunk into mere valley glaciers, and while it still occupied part of the lower ground, there would doubtless be a copious discharge of water from its melting front. As the ice had overridden the land and buried its minor inequalities, there would be great diversity in the level of the bottom of the ice, and consequently the escaping water would at first flow with little relation to the present main drainage lines. Streams of water might be let loose over the plateaux and hilly ridges as well as over the plains. There could hardly, therefore, fail to be much rearrangement of the general covering of detritus left by the ice. In the more important valleys, also, in the upper part of which glaciers still lingered, there would be a copious discharge of water, with the consequent sweeping of much glacial detritus to lower levels. In some regions, such as that of the broad strath of the River Spey, there seems to have been a combination of ice work and river-transport, the glacier descending in tongues into the valleys and breaking up into blocks which, during times of more rapid thaw, were swept to lower levels and stranded on banks of shingle and sand. Sometimes these ice-masses were of considerable size, and when, after they had been surrounded by the sediment, they eventually melted their sites were marked by deep kettle-hole or cauldron-like hollows in the drift. Successive terraces in the fluvio-glacial drift mark levels of the rivers as the volume of water gradually diminished and the channel was lowered by the scour of the floods.[1]

To this part of the Ice Age and to the result of the melting of the snow-fields, the masses of gravel and sand which over so much of Northern Europe rest on boulder-clay may with probability be attributed. Among these accumulations are the sheets of coarse, well-rounded gravel (plateau-gravel), which, with no recognisable relation to the present contours of the ground, are spread over the plains and low plateaux, and fill up many valleys. These gravels rest sometimes on boulder-clay, sometimes on solid rock, and are older than the lower valley alluvia. They have evidently not been formed by any ordinary river action, nor is it

[1] For an account of the fluvio-glacial deposits of Strathspey see Hinxman, *Summary of Progress of Geol. Surv.* 1897, p. 147.

easy to see how the sea can have been concerned in their formation. They are well developed in Norfolk and adjacent tracts of the south-east of England, where they consist mainly of well-rounded flints (cannon-shot gravel).

Still more remarkable are the accumulations of sand and gravel known as the "Kame" or "Esker" series. Covering the lower ground in a sporadic manner, often tolerably thick on the plains, these deposits rise up to heights of 1000 feet or more. In some places, they cannot be satisfactorily separated from the sands and gravels associated with the boulder-clay, in others they seem to merge into the sandy deposits of the raised beaches, while in hilly tracts it is sometimes hard to distinguish between them and true moraine-stuff. Their most remarkable mode of occurrence is when they assume the form of mounds and ridges, which run across valleys and plains, along hillsides, and even over water-sheds. Frequently these ridges coalesce so as to enclose basin-shaped hollows, which are often occupied by tarns. Many of the most marked ridges are not more than 50 or 60 feet in diameter, sloping up to the crest, which may be 20 or 30 feet above the plain. A single ridge may occasionally be traced in a slightly sinuous course for many miles, as in the case of the famous mound which runs across the centre of Ireland.[1] These ridges, known in Scotland as Kames, in Ireland as Eskers, and in Scandinavia as Ösar, consist sometimes of coarse gravel or earthy detritus, but more usually of clean, well-stratified sand and gravel, the stratification towards the surface corresponding with the external slopes of the ground, in such a manner as to prove that the ridges are usually original forms of deposit, and not the result of the irregular erosion of a general bed of sand and gravel. Some writers compared these features to the submarine banks formed in the pathway of tidal currents near the shore; but by general consent this explanation has long been abandoned. Geologists are now agreed in regarding them as of terrestrial origin, connected in some intimate way with the great snow-fields and glaciers. Some observers have referred them to the accumulation of detritus in channels or tunnels under the ice.[2] Others have regarded them as due rather to the action of streams which flowed at first on the surface of the ice and gradually worked their way through it to the bottom.[3] Nothing quite like true Kames has been observed along the margins of the Greenland inland ice, where they have been diligently looked for. It must be admitted that no wholly satisfactory explanation of their mode of formation has yet been given.

Over the tracts from which the ice-sheet retired, lakes are usually scattered in large numbers. Some of these lie in ice-worn basins of

[1] See Sollas, *Sci. Trans. Roy. Dublin Soc.* v. (1896), p. 785, where a map of the Irish eskers is given.

[2] This view is well stated by Prof. Davis, *Proc. Boston Soc. Nat. Hist.* xxv. p. 278.

[3] This opinion, stated by Prof. N. H. Winchell as far back as 1872 (*Ann. Rep. Geol. Survey, Minnesota*, 1872, p. 62), has been enforced by Mr. W. O. Crosby, whose latest presentation of the subject will be found in the *American Geologist*, vol. xxix. p. 1 (July 1902).

rock. Where the detritus has been strewn thickly over the ground, however, they rest in hollows of the clay, earth, sand, or gravel. The origin of these depressions in the drifts cannot be found in any denuding operation since the ice left. They are obviously original features of the surface, dating back to the time when the various drifts were laid down. In some cases they may be due to irregular deposition of the detritus, as where successive moraines are thrown across a valley. The small pools may sometimes have been originated by the melting of portions of ice which had become detached from the main mass, and were surrounded by or buried under detritus, like the ice-blocks in the fluvio-glacial series above alluded to. Many small rock-basins may have had their place and form determined by that prolonged deep subaerial rotting already referred to, while others of large size may be referable to underground movements. But the glaciers, in smoothing and polishing the rocks, wore them down unequally, hollowing them into rock-basins, leaving them in prominent smoothed domes, and carrying the same characteristic sculpture over all the durable rocks exposed in the areas of intenser glaciation.

The emergence of the land in Scandinavia and Britain took place interruptedly. During its progress it was marked by long pauses when the level remained unchanged, when the waves and floating ice cut ledges along the sea-margin, and when sand and gravel were accumulated below high-water mark in sheltered parts of the coast-line. These platforms of erosion and deposit (raised beaches) form conspicuous features at successive heights above the present level of the sea (p. 383). The coast of Scotland is fringed with a succession of them (Fig. 493). Those below the level of 100 feet above the sea are often remarkably fresh. The 100-feet terrace forms a wide plateau in the estuaries, such as those of the Forth, Tay, and some of the northern firths. As above mentioned, its clays contain an Arctic fauna, which includes the ringed seal or floe-rat (*Phoca hispida*), the smallest of the now living Arctic seals. A terrace at the level of 50 feet is conspicuous also on both sides of Scotland, being especially prominent among the western fjords. In Scandinavia, especially in the northern parts of Norway, the successive pauses in the last uprise of the land are impressively revealed by long lines of terraces which wind around the hill-slopes that encircle the fjords (pp. 384, 386).

The records of the closing ages of the long and varied Glacial Period merge insensibly into those of later geological times. It is obvious that besides the effect of a general change of climate operating over the whole of the northern hemisphere, we must remember the influence which the natural features of different countries had upon the climate. From the plains, the ice and snow would retire sooner than from the hills. In fact, we may regard some parts of Europe as still retaining the conditions of the Glacial Period, though in diminished intensity, the present glaciers of the Alps being, as above remarked, the representatives in continuous succession of the vaster sheets that once descended into the lowlands on all sides from that central elevated region. And even where the ice has long since disappeared, there remain, in the living plants and animals of the

higher and colder uplands, witnesses to the former severity of the climate. As that severity lessened, the Arctic vegetation, that had spread over the lower grounds of central and western Europe, was there extirpated before the advance of plants loving a milder temperature, which had doubtless been natives of Europe before the period of great cold, and which were now enabled to reoccupy the sites whence they had been banished. On the higher mountains, where the climate is still not wholly uncongenial for them, and likewise here and there at lower levels, colonies of the once general Arctic flora still survive. The Arctic animals have also been mostly driven away to their northern homes, or have become wholly extinct. But the remains of the Arctic plants and to some extent also of the animals occur in the lacustrine clays, peat-mosses, and other deposits of the glacial series, even down into the heart of Europe (p. 840).

It has been forcibly pointed out by Mr. Wallace that the present mammalian fauna of the globe presents everywhere a striking contrast to the extraordinary variety and great size of the mammals of the

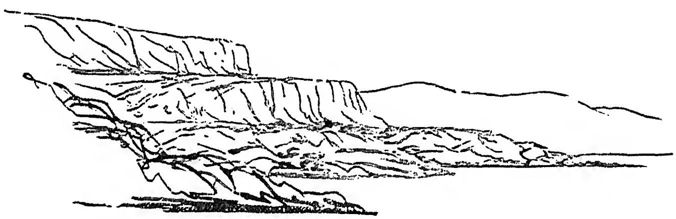

Fig. 403.—Terraces of erosion, marking ancient shore-lines. South coast of Island of Mull.

Tertiary periods. "We live," he says, "in a zoologically impoverished world, from which all the largest, and fiercest, and strangest forms have recently disappeared."[1] He connects this remarkable reduction with the refrigeration of climate during the Glacial Period. The change, to whatever cause it may be assigned, is certainly remarkably persistent in the Old World and in the New, and not merely in the temperate and northern regions, but even as far south as the southern slopes of the Himalaya Mountains.

The cause of the remarkable change of climate during late Tertiary and post-Tertiary time has given rise to much discussion, but is still without a completely satisfactory explanation. Some writers have favoured the view that there has been a change in the position of the earth's axis (p. 24), or of its centre of gravity (p. 28). Others have suggested that the earth may have passed through hot and cold regions of space. Others, again, and notably Lyell, have called in the effects of stupendous terrestrial changes in the distribution of land and sea, on the assumption that elevation of land about the poles must cool the temperature of the globe, while elevation round the equator would raise it. But the amount of geographical transformation thus involved was

[1] 'Geographical Distribution of Animals,' i. p. 150. Consult also Asa Gray, *Nature*, xix. p. 327 (363).

so great and the evidence for it appeared to be so slender that geologists generally have been reluctant to accept this explanation. In the difficulty of accounting for the phenomena by any feasible operation on the earth itself, they by degrees accustomed themselves to the belief that the cold of the Glacial Period was not due to mere terrestrial changes, but was to be explained somehow as the result of cosmical causes.

Sir John Herschel [1] had already pointed out that the direct effect of a high condition of eccentricity of the earth's orbit is to produce an unusually cold winter, followed by a correspondingly hot summer, in the hemisphere whose winter occurs in aphelion, while an equable condition of climate at the same time prevails on the opposite hemisphere. But as both hemispheres must receive precisely the same amount of solar heat, because the deficiency of heat, resulting from the sun's greater distance during one part of the year, is exactly compensated by the greater length of that season, he considered that the direct effects of eccentricity must thus be nearly neutralised.[2] Subsequently the question of the effects of eccentricity was taken up by the late James Croll, who maintained that a series of physical changes on the earth's surface would result indirectly from an increase of eccentricity, and that in this way a great alteration would be effected in the distribution of terrestrial climates. He thought that with the eccentricity at its superior limit and winter at aphelion the reduction of the midwinter temperature would be so great that in temperate latitudes the precipitation would take the form of snow rather than rain, that this snow, lying from season to season and year to year, would lower the summer temperature, giving rise to fogs that would intercept the sun's rays, that the trade winds and consequently the ocean currents would be weakened or deflected, and thus that a period of extreme cold would be introduced all over the northern part of the hemisphere. He argued further that these conditions would eventually be shifted to the other hemisphere when its winter occurred in aphelion, and that there would consequently be an alternation between extreme cold and perpetual summer. In this way he accounted for the evidence furnished by fossil plants that the climate of the Arctic regions was formerly genial, and also for the existence of interglacial warm periods.[3] These views were adopted and enforced with additional arguments by Sir Robert Ball,[4] and they were widely accepted by geologists who were glad to be put in possession of what they regarded as a probable solution of difficulties which had so long confronted them.

But meteorologists and physicists were less confident of the value of Croll's methods and results. Even in his lifetime he had to defend his views from the attack of Professor Simon Newcomb,[5] and since his death they have been destructively criticised by Mr.

[1] *Trans. Geol. Soc.* vol. iii. p. 293 (2nd series).

[2] 'Cabinet Cyclopædia,' sec. 315; 'Outlines of Astronomy,' sec. 368.

[3] *Phil. Mag.* xxviii. (1864), p. 121. His detailed researches will be found in his volume 'Climate and Time,' 1875, and his later work 'Discussions on Climate and Cosmology.'

[4] 'The Cause of an Ice Age,' London 1891.

[5] See *Phil. Mag.* for 1876, 1883, and 1884.

E. P. Culverwell, who regards them as "a vague speculation, clothed indeed with a delusive semblance of severe numerical accuracy, but having no foundation in physical fact, and built up of parts which do not dovetail one into the other."[1] This writer affirms that Croll's fundamental assumption that the midsummer and midwinter temperatures are directly proportional to the sun's heat at those seasons, is not borne out by an appeal to observation. At Yakutsk, for example, which may be taken as an extreme case of range of temperature, if the excess of its midwinter temperature above that of space were due entirely to the midwinter sun-heat, then the midsummer temperature, also arising solely from direct sun-heat, should be 5800° Fahr. above that of space, or if the midsummer excess were due only to the midsummer sun-heat, then the midwinter temperature ought to be $-228°$ Fahr. Calculating what parallels of latitude now receive the same amount of winter sun-heat as the parallels of 40°, 50°, 60°, 70°, 80°, and 90° received during a time of high eccentricity when winter occurred in aphelion, Mr. Culverwell found that the daily average of sun-heat received during the winter of high eccentricity by the parallel of 40° is now received by that of 42·2, and that the parallel of 54° at the present time receives the same amount as that of 50° did then. He concludes that the lowering of the midwinter temperature from lat. 50° N. to 70° N., due to diminished winter sun-heat in the epoch of great eccentricity, cannot have been as much as from 3° to 5° Fahr. Such a small decrease could not have been sufficient to produce a glacial period within these latitudes. But it is not certain that the midwinter temperature would really fall during the epoch of maximum eccentricity. This temperature, in the case of the British Isles, depends not on direct sun-heat so much as on the heat transported by the Gulf-stream. But during the time of high eccentricity, the summer temperature of the regions whence that stream derives its warmth was greater than it is now, so that it is conceivable that, instead of being colder in winter, the British climate may actually have been milder than at present.

Thus the failure of the astronomical theory to afford a solution of the problem of the Ice Age has left geologists once more face to face with their difficulties. But the question is so fascinating that it continues to engage attention and to suggest speculation. Among the recent attempts to deal with it reference may be made here to the hypothesis proposed by Professor Chamberlin on the basis of variations in the amount of carbon dioxide in the air. Reference has already (p. 36) been made to the capacity of that gas for absorbing heat and to the effect that might be produced on the temperature of the air by even a comparatively small increase or diminution in the proportion of the gas. The suggestion is that while there is a general tendency to the diminution of that proportion there arise from time to time conditions, such as great volcanic discharges, whereby much carbonic dioxide is supplied to the atmosphere. On this view the Glacial Period would mark a time of great depletion of the gas, while the Arctic Miocene flora would indicate a time of comparative

[1] *Geol. Mag.* 1895, pp. 3, 55; *Phil. Mag.* 1894, p. 541.

enrichment.[1] Other geologists have turned back to the idea of geographical changes. That considerable oscillations of the relative levels of land and sea took place during the Ice Age has been clearly determined. The general result of investigation favours the opinion that the land in the early part of that period stood much higher than now over the northern regions of Europe and North America. If we accept the conclusions drawn from the prolongation of land-valleys upon the sea-floor to a depth of many hundred feet, and from the distribution of dead littoral and shallow-water shells down to depths of 6000 or 8000 feet in the North Atlantic, we can see that a vast area of high land would, under these conditions, have existed. This higher elevation would undoubtedly tend to lower the temperature. Some of the upraised parts of the sea-floor might deflect warm ocean currents and thus still further increase the cold in the higher latitudes. But no satisfactory attempt has yet been made to trace out these changes geographically on actual evidence of their having occurred, and to connect them with the phenomena of the Pleistocene period.[2] We must meanwhile suspend judgment. Probably no one cause will be found sufficient to explain all the difficulties of the problem. But we may hope that from the constant and enthusiastic researches in this subject which are in progress over so large a portion of the earth's surface, the solution will eventually be attained.

§ 2. Local Development.

Britain.[3]—Though the generalised succession of phenomena above given is usually observable, some variety is traceable in the evidence in different parts of the British

[1] *Journ. Geol.* v. (1897), p. 653 ; viii. (1900), pp. 545, 667, 752.

[2] Some suggestive remarks on this subject by Mr. W. Upham will be found in the Appendix to Wright's 'Ice Age in North America' (1889) ; also in *Bull. Geol. Soc. Amer.* i. (1889) p. 563, x. (1898) p. 5 ; and *Amer. Geol.* vi. (1890), p. 327, xxix. (1902) p. 162.

[3] Besides the general works and papers already cited, the following special papers in the *Quarterly Journal of the Geological Society* may be consulted : *Wales*, Mackintosh, 1882, p. 184 ; T. W. E. David, 1883, p. 39 ; T. Mellard Reade, liii. (1897), p. 341. *N.W. England*, Mackintosh, 1879, p. 425 ; 1880, p. 178 ; T. M. Reade, 1874, p. 27 ; 1883, p. 83 ; 1885, p. 102 ; 1897, p. 341 ; 1898, p. 582 ; A. Strahan, 1886, p. 369. *S.E. England*, Searles V. Wood, jun., 1880, p. 457 ; 1882, p. 667 ; A. J. Jukes-Browne, 1879, p. 397 ; 1883, p. 596 ; Rowe, 1887, p. 351. *N.E. England*, G. W. Lamplugh, xlvii. (1891), p. 384 ; P. F. Kendall, lviii. (1902), p. 471 ; A. R. Dwerryhouse, *op. cit.* p. 572. *Scotland* (Long Island), J. Geikie, xxix. (1873) ; xxxiv. (1878) ; (Shetlands) Peach and Horne, 1879, p. 778 ; (Orkneys) 1880, p. 648 ; (Aberdeenshire) T. F. Jamieson, 1882, pp. 145, 160. The first detailed account of the Scottish Boulder-clay and later glacial deposits was given by me as far back as 1863 in the first volume of the *Trans. Geol. Soc. Glasgow*, already cited. The student will find a useful digest of the literature for England up to 1887 in Mr. H. B. Woodward's 'Geology of England and Wales.' The *Memoirs* and the *Summary of Progress of the Geological Survey* contain much local detail on this subject. The 'Papers and Notes on the Glacial Geology of Great Britain and Ireland' (1894), by the late H. Carvill Lewis, gives an account of the glaciation as seen by the eye of an American glacialist. Mr. W. Jerome Harrison's "Bibliography of Midland Glaciology," *Proc. Birmingham Nat. Hist. Phil. Soc.* ix. (1895), will be found of great service for the Midlands.

area. In Scotland, where the ground is generally more elevated, and where snow and ice were most abundant, the phenomena of glaciation reached their maximum development. Striæ are preserved on rock-surfaces at heights of more than 3000 feet in the north-west Highlands, and as the fjords and sea outside are in places more than 100 fathoms deep, the total thickness of ice in that region may have reached 5000 feet. In the high grounds of England, Wales, and Ireland there was likewise extensive accumulation of ice. The ice-worn rocks of the low grounds are usually covered with boulder-clay, which in Scotland is interstratified with beds of sand, fine clay, and peat, and has yielded marine organisms in the lowland districts up to a height of 1061 feet. In England, marine shells and foraminifera, usually fragmentary, occur in the boulder-clays both in the eastern and western counties. The ice-sheet no doubt passed over some parts of the sea-bottom, and ground up the shell-banks that happened to lie in its way, as has happened, for example, in Caithness, Holderness, East Anglia, and throughout the basin of the Irish Sea, where the shells in the boulder-clay are fragmentary, and sometimes ice-striated. The "Bridlington Crag" of Yorkshire, according to Messrs. Sorby, Lamplugh, and Reid, is a large fragment torn from a submarine shell-clay, and imbedded in the boulder-clay.[1] Its shells are strikingly Arctic.

The depth, extent, and movements of the great ice-sheet which covered Britain have been indicated in the foregoing pages. The proofs of the former presence of the ice are scattered abundantly over the country north of a line drawn from the Bristol Channel to the estuary of the Thames. South of that line the ground is free from boulder-clay, though various deposits, possibly of contemporary date, serve to indicate that, though not buried under ice, this southern fringe of England had its own glacial conditions.[2] Among these is the "Coombe-rock" of Sussex—a mass of unstratified rubbish which has been referred by Mr. C. Reid to the action of heavy summer rains at a time when the ground a little below the surface was permanently frozen. In the glaciated tract one of the most striking features in showing the Greenland-like massiveness of the ice-sheet is furnished by the south of Ireland, where the hills of Cork and Kerry have been ground smooth and striated down to the sea, and even under sea-level, detached islets appearing as well ice-rounded *roches moutonnées*. There can be no doubt from this evidence that even in the south of Ireland the ice-sheet continued to be so massive that it went out to sea as a great wall of ice, probably breaking off there in icebergs.

The records of the submersion of Britain are probably very incomplete. If we rely only on the evidence of untransported marine shells, we obtain the lowest limit of depression. But, as above remarked, the mere presence of marine organisms cannot always be accepted as conclusive. The renewed ice and snow, after re-elevation, may well have destroyed most of the shell-beds, and their destruction would be most complete where the snow-fields and glaciers were most extensive. Beds of sand and gravel with recent shells have been observed on Moel Tryfaen, in North Wales, at a height of 1350 feet, but the shells are broken and show such a curious commingling of species as to indicate that they are probably not really in place.[3] In Cheshire marine shells occur at 1200 feet. In Scotland they were said to have been obtained at 524 feet in the boulder-clay of Lanarkshire; but an examination of the locality by a Committee of the British Association has failed to discover any proof of the existence of shells there.[4] On the other hand, the same Committee reported that at Clava, near Inverness, a shell-bearing clay contains abundant foraminifera and mollusks, including Arctic forms (*Nuculana* [*Leda*] *pernula*, *Nuculana tenuis* [*Leda pygmæa*], *Tellina* [*Macoma*] *calcarea*,

[1] Lamplugh, *Q. J. G. S.* xl. (1884), p. 312. C. Reid, "Geology of Holderness," in *Mem. Geol. Survey*.

[2] C. Reid, *Q. J. G. S.* xliii. (1887), p. 364.

[3] See T. Mellard Reade, *Proc. Liverpool Geol. Soc.* 1893, p. 36; Report of a Committee on Moel Tryfaen, *Brit. Assoc.* 1899, with a good bibliography of the locality.

[4] *Brit. Assoc.* 1894.

Natica pallida [*grœnlandica*]) and others still common in British seas. The condition of these remains indicates that they probably lived and died on the spot, which is 500 feet above sea-level, and that the submergence amounted at least to that extent.[1] Subsequent elevation of the land has brought up within tide-marks some of the clays deposited over deeper parts of the sea-floor during the time of the submergence. In the Clyde basin and in some of the western fjords, these clays (Clyde Beds) are full of foraminifera and shells which are unquestionably in their original positions. Comparing the species with those of the adjacent seas, we find them to be more boreal in character; although nearly the whole of the species still live in Scottish seas, a few are extremely rare. Some of the more characteristic northern shells in these deposits are *Pecten islandicus*, *Tellina* (*Macoma*) *calcarea*, *Portlandia glacialis* (*Leda truncata*), *Yoldia* (*Leda*) *lanceolata*, *Portlandia* (*Yoldia*) *arctica*, *Saxicava rugosa*,

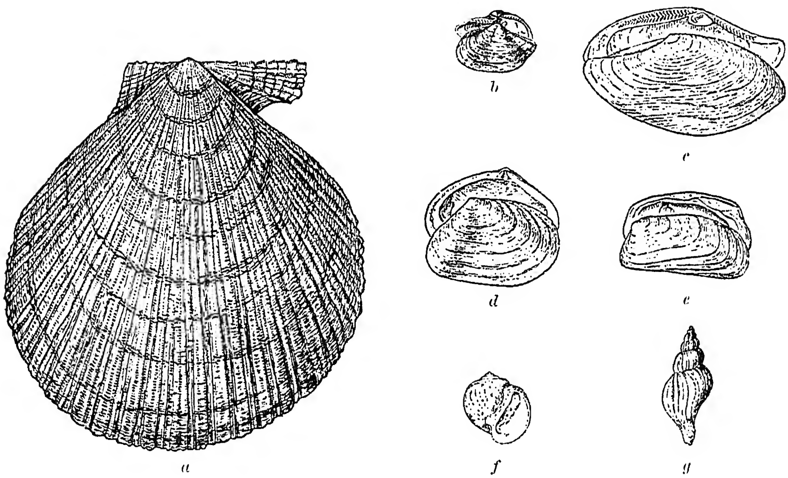

Fig. 494.—Group of Shells from the Scottish Glacial Beds.

a, Pecten (Chlamys) islandicus, Müll. (½); *b*, Portlandia glacialis, Gray (½); *c*, Yoldia lanceolata, Sow. (½); *d*, Tellina (Macoma) calcarea = lata, Gmelin (½); *e*, Saxicava rugosa, Linn. (½); *f*, Natica affinis, Gmelin (= clausa, Brod, and Sow.) (½); *g*, Trophon scalariformis, Gould (T. clathratus) (½).

Panopæa norvegica, *Trophon scalariformis* (*T. clathratus*), and *Natica affinis* (*clausa*) (Fig. 494). The clays in which these organisms lie are often exceedingly fine and unctuous, with occasional stones (sometimes striated) scattered through them. This material has probably been a glacier-mud; and the stones have been floated off on ice-rafts.

Of the later stages of the Glacial Period, the records are much the same all over Britain, allowance being made for the greater cold and longer lingering of the glaciers in the north than in the south, and among the hills than on the plains.

In Scotland the following may be taken as the average succession of glacial phenomena in descending order:—

Last traces of glaciers, small moraines at the foot of corries among the higher mountain groups. The glaciers lingered longest among the higher mountains of the north-west (Highlands, Southern Uplands, and detached islands, such as Arran, Skye, Hoy, Harris, &c.).

[1] *Op. cit.* 1893; see also the Committee's Report for 1896, which contains an account of the shell-beds of Cantyre, Argyllshire, at heights varying up to about 200 feet.

Marine terraces (50 feet and higher). Clay-beds of the Arctic sea-bottom (Clyde Beds) containing northern mollusks. The highest well-marked and persistent marine terrace proves a submergence of at least 100 feet beneath the present level of the land, and its organic remains tell that the climate was still Arctic.

Large moraines, showing that after the re-emergence of the land glaciers descended to the line of the present sea-level in the north-west of Scotland. Some of the moraines rest upon the 50-feet marine terrace.

Erratic blocks, chiefly transported by the first ice-sheet, but partly also by the later glaciers, and partly by floating ice during the period of submergence.

Sands and Gravels—Kame or Esker series, sometimes containing terrestrial organisms, sometimes marine shells.

Upper Boulder-clay—rudely stratified clays with sands and gravels; the stones almost wholly from the rocks of the country, but sometimes (basin of Forth) including pieces of chalk and flint.

Till or Lower Boulder-clay (bottom moraine of the ice-sheet)—a stiff stony unstratified clay, varying up to 150 feet or more in thickness. Its contained boulders and pebbles are native to the country, and can usually be assigned to their source. It includes bands of fine sand, finely laminated clays, occasional layers of peat and terrestrial vegetation, with bones of mammoth and reindeer; also on the lower grounds and up to heights of 1300 feet or more, dispersed foraminifera together with fragmentary Arctic and boreal marine shells, which occur both in the till and in intercalated layers of laminated clay and sand. The till spreads over the lower grounds, often taking the form of ridges or drums (drumlins), which run on the whole in the lines of chief glaciation.

Ice-worn rock surfaces.

Over a great part of England and Ireland the drift deposits are capable of subdivision as follows:—

4. Moraines (North Wales, Lake District, &c.) and youngest raised beaches.[1]
3. Upper Boulder-clay—a stiff stony clay or loam with ice-worn stones and intercalations of sand, gravel, or silt. It occasionally contains marine shells. It possibly does not come south of the Wash.
2. Middle Sands and Gravels, containing marine shells. At Macclesfield (1200 feet above the sea) there have been found *Meretrix chione*, *Cardium rusticum*, *Arca* (*Barbatia*) *lactea*, *Tellina* (*Macoma*) *balthica*, *Cyprina islandica*, *Astarte borealis*, and other shells now living in the seas around Britain, but indicating perhaps by their grouping a rather colder climate than the present. *Corbicula fluminalis* abounds in some gravels which underlie the upper boulder-clay. South of the Wash it is found in similar deposits overlying the lower or "chalky boulder-clay."[2] In Ireland marine shells of living British species occur at heights of 1300 feet above the sea.[3]
1. Lower Boulder-clay—a stiff clayey deposit stuck full of ice-worn blocks, and equivalent to the Till of Scotland. On the east coast of England (Holderness, Lincoln, and Norfolk) it contains fragments of Scandinavian rocks; in particular, gneiss, mica-schist, quartzite, granite, syenite, rhombenporphyr; also pieces of red and black flint, probably from Denmark, and of Carboniferous limestone and sandstone, which have doubtless travelled from the north.[4] Along the Norfolk cliffs it presents stratified intercalations of gravel and sand, which have been extraordinarily contorted. As in Scotland, the true lower boulder-clay in the north of England and Ireland is often arranged in parallel ridges or drums in the prevalent line of ice-movement. As above mentioned, the "crag" of Bridlington, Yorkshire, is probably a fragment of an old marine glacial shell-bearing clay, torn up and imbedded in the boulder-

[1] In Gower, South Wales, Mr. Tiddeman has shown that the raised beach there is overspread with various glacial deposits. *Geol. Mag.* 1900, pp. 440, 528.

[2] On this characteristic form of till, see H. B. Woodward, *Geol. Mag.* 1897, p. 485.

[3] On the Irish shell-bearing drifts ("manure gravels of Wexford") see Reports of Committee; *Brit. Assoc.* 1887-1890; W. J. Sollas and R. L. Praeger, *Irish Naturalist*, iii. (1894), pp. 17, 161, 194; iv. (1895), p. 321; T. Mellard Reade, *Proc. Liverpool Geol. Soc.* 1893-94.

[4] V. Madsen, *Q. J. G. S.* xlix. (1893), p. 114.

clay of the first ice-sheet. The Arctic fresh-water bed (p. 1288) may be intercalated here.

The southern limit of the ice has been already mentioned (p. 1305). No "terminal moraine" has been observed, the ground to the south of the ice-limit being free from glaciation, though erratic blocks, probably brought by drift-ice, are found on the Sussex coast.[1] The Coombe-rock lies outside the limits of the ice-sheet. Deep superficial accumulations of rotted rock occur where the rock has decomposed *in situ* in the southern non-glaciated region, as may be well seen over the Palæozoic slates and granites of Devon and Cornwall. In the non-glaciated Chalk districts, a thick cover of flints and red earth partly represents the insoluble parts of the chalk that remain after prolonged subaerial decay, but from the frequent presence of fragments of quartz, which does not occur in the chalk, this mantle of "clay with flints" seems to indicate also a certain amount of transport. The high moorlands of eastern Yorkshire appear to have risen as an insular tract above the ice-sheet; for the boulder-clay advances up the valleys that indent the northern face of the Jurassic table-land, but ceases at a height of about 800 feet, and the table-land itself is entirely free of drift, but its rocks are much decayed at the surface. Mr. Kendall has traced the existence of a system of glacier lakes in this district caused by the ponding of the inland drainage against the front of the ice-sheet.[2]

Scandinavia and **Finland.**[3]—The order of Pleistocene phenomena is generally the same here as in Britain. The surface of the country has been everywhere intensely glaciated, and, as already stated, the ice-striæ and transported stones show that the great ice-sheet probably exceeded 5000 feet in thickness, for the hills are ice-worn for more than that height above sea-level. Moving outwards from the axis of the peninsula the ice passed down the western fjords into the Atlantic, southwards and south-eastwards into the Gulf of Bothnia, across Finland and the basin of the Baltic into Russia, Northern Germany, Denmark and Holland, and south-westwards into the hollow of the North Sea, which it crossed to the south-east of England. Besides the ordinary morainic materials left behind on the melting of the ice, a marked deposit is that of the terminal moraines (*Ra's*) which have been traced across the south of Norway and Sweden, and which reappear and run completely across the southern part of Finland. These huge persistent mounds of glacial rubbish follow each other at variable distances in roughly parallel lines, which mark successive pauses in the shrinking of the ice-sheet. There is evidence also of the retreat of the ice from some parts of the country while it still covered adjoining tracts and ponded back the drainage, thus giving rise to glacial lakes. The margins of these vanished sheets of water can be traced in lines of "parallel roads."[4]

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[1] C. Reid, *Q. J. G. S.* xlviii. (1892), p. 344; xlix. p. 325.

[2] *Q. J. G. S.* lviii. (1902). In this paper the movements of the several ice-streams which united to form the great ice-sheet of England are discussed.

[3] The glacial literature of this region is now abundant. Among the later writers may be mentioned J. Ailio, G. Andersson, H. Berghell, W. C. Brögger, G. de Geer, O. Gumaelius, A. M. Hansen, H. Hedström, A. Hollender, G. Högbom, J. H. Holmberg, N. O. Holst, J. C. Moberg, H. Munthe, W. Ramsay, H. Reusch, J. J. Sederholm, A. E. Törnebohm. Numerous contributions from these and other writers have appeared in *Fennia*, the *Geol. Fören. Stockholm*, and the papers of the Swedish, Norwegian, and Finland Geological Surveys. A general resume of the subject with special reference to Sweden will be found in Nathorst's 'Sveriges Geologi.' A brief notice of the glacial history of Finland is supplied by Sederholm in the Text accompanying the 'Atlas de Finlande,' published in 1899, and an excellent account of the glacial phenomena of the Kola peninsula between the Arctic Ocean and the White Sea is given by W. Ramsay in *Fennia*, xvi. No. 1 (1898). The later glacial phenomena of Southern Norway are treated in ample detail and with conspicuous acumen by Brögger in the important monograph already cited. Col. H. W. Fielden has described the glacial geology of Arctic Europe and its islands in *Q. J. G. S.* lii. (1896), pp. 52, 721.

[4] A remarkable example of this feature has been described from Central Jemtland in Sweden by Gunnar Andersson, where, by the persistence of the Bothnian ice-sheet, while the

After the maximum extension of the glaciation, a general subsidence of the region took place, and the lower grounds were submerged. At the time of the greatest spread of the sea (which at Christiania is indicated by a boundary line at 216 metres, pointing to a maximum submergence of about 700 feet), an open sound connected the Skager Rak across Sweden with the Gulf of Bothnia, which then covered most of Finland, and was connected by a narrow strait with the White Sea. At this time the *Yoldia*-clay was accumulated, in which twenty-four species of shells have been found, of which six do not now live in Scandinavian waters, but still exist in the Kara Sea, viz. *Portlandia arctica*, *Yoldia hyperborea*, *Sipho togatus*, *S. brevispira*, *Buccinum terræ-novæ*, and *Neptunea despecta*; while eight (including *Pecten islandicus*, *Natica affinis* or *clausa*, and *Trophon truncatus*) have disappeared from the southern parts of the country, but are still found in the Arctic part of the coast. Professor Brögger has shown that this clay is only found outside the great terminal moraine ridge or *ra*, a circumstance which indicates that the ice-sheet there still descended to the sea and kept the ground inside from being submerged under salt water. As already stated, he notices the occurrence of the shallow-water fauna of the *Yoldia*-clay at great depths in the Norwegian seas, and believes that it points to the probability of the land having stood, at the time of the great ice-sheet, at least 2600 metres higher than it does now. Above the *Yoldia*-clay comes the *Arca*-clay, in the oldest part of which the shells are still Arctic, but in the youngest part (*Portlandia*-clay, *Mya*-banks) half are boreal, with a trace of the advent of southern forms. In the overlying *Mytilus*-clay and *Cardium*-clay the proportion of Arctic forms falls to a third or a quarter, while the boreal forms increase to a half of the whole, with from an eighth to a fourth of Lusitanian forms. Successive stages in the uprise of the land are marked by the raised beaches, to which reference has already been made.

One of the most remarkable features of the period which succeeded the submergence of Scandinavia was the conversion of the wide basin of the Baltic, Gulf of Bothnia and Gulf of Finland into a vast ice-dammed lake or inland fresh-water sea, having an area which has been estimated by De Geer at 570,000 square kilometres, that is, about as large as the Caspian Sea, Lake Superior, and Lake Michigan all joined into one. The records of this vast expanse of fresh water are to be seen in sheets of clay and sand found at many places all round the coasts up to heights of more than 100 feet above the present sea-level. These deposits contain lacustrine shells (*Limnæa ovata*, *L. palustris*, *Planorbis contortus*, *P. marginatus*, *Valvata cristata*, *Bithinia tentaculata*, *Pisidium*, several species, and especially the little limpet-like *Ancylus fluviatilis*), and have received the name of *Ancylus*-group.

Interesting evidence of the gradual disappearance of the Arctic climate is supplied by the older parts of the peat-mosses, where such plants as *Salix polaris* and *Betula nana*, and the remains of the little Arctic phyllopod crustacean *Apus glacialis* are preserved, while the deposits of calc-sinter have yielded leaves of hazel and other plants of a less northern type. While these climatal changes were in progress the general level of the region, which at the time of the *Ancylus*-sea was higher than at present, began once more to sink until the maritime low grounds all round Scandinavia, Finland, and Esthonia were submerged. There were then deposited the clays and sands which have received the name of the *Littorina*-group, from the common gasteropods in them (*Littorina litorea*, *L. rudis*, *Cardium edule*, *Mytilus edulis*). A subsequent movement of elevation has brought the land up to its present position.[1]

ground to the west was clear of ice, the drainage of the valleys was dammed up, and a large lake was formed which for a time increased in size as the ice shrank and laid bare more ground. The successive stages in the development and diminution of the lake can still be made out. "Den centraljämtska Issjön," *Ymer*, 1897, H. 1, p. 42.

[1] A valuable contribution to the discussion of the extent and amount of the submergence of Southern Finland in the Yoldia and Littorina seas has been made by H. Berghell of the

Germany.[1]—Since the year 1878 an active exploration of the earlier memorials of the Glacial Period has been carried on in Northern Germany, with the result of bringing out more clearly the evidence for the prolongation of the Scandinavian and Finland ice across the Baltic and the plains of Germany even into Saxony. The limits reached by the ice are approximately fixed by the line to which northern erratics can be traced. Beneath the oldest members of the glacial drifts, deposits are found in a fragmentary condition containing shells now living only in Southern Europe, such as *Viviparus diluviana* and *Corbicula fluminalis*. Above the glaciated rocks comes a stiff, unstratified clay, with ice-striated blocks of northern origin—the till or boulder-clay (Geschiebelehm, Blocklehm). Two distinct boulder-clays have been recognised —the older or till separated by interglacial deposits from the newer. Terminal moraines marking the limits of the ice-sheet have been found in the form of ramparts of Scandinavian blocks and gravel, which have been traced for many miles along the coast-line and across the plains of Northern Germany.[2] The sources of the various ice-streams which united to form the great ice-sheet that crept over the Germanic plain are well shown by a study of the stones in the moraine material. The Scandinavian rocks are found towards the west and the Finnish towards the east of the glaciated area. Successive pauses in the retreat of the ice-sheet have been recognised in the boulder-ramparts, in belts of mounds that were formed at the melting edge of the ice, and in the sheets of sand and gravel spread out beyond.[3] At the southern edge of the northern drift at Deuben, a little south from Dresden, remains of an Arctic flora have been found, comprising leaves of *Salix herbacea*, *S. retusa*, *Polygonum viviparum*, *Saxifraga oppositifolia*, *S. hirculus*, remains of *Carices* and mosses with *Succinea oblonga* and fragments of beetles.[4] Among the intercalated materials that separate the two boulder-clays are layers of peat, with remains of pine, fir, aspen, willow, white birch, hazel, hornbeam, poplar, holly, oak, juniper, ilex, and various water-plants, in particular a water-lily no longer living in Europe. With this vegetation are associated remains of *Elephas antiquus*, mammoth, rhinoceros, elk, megaceros, reindeer, musk-sheep, bison, bear, &c. Some of the interglacial deposits are of marine origin on the lower grounds bordering the Baltic, for they contain *Cyprina islandica*, *Portlandia arctica*, *Tellina* (*Macoma*) *balthica* (*solidula*), &c. Among the youngest glacial, and probably in part interglacial, deposits are the upper sands and gravels (Geschiebedecksand), which spread over wide areas of the Germanic plain, partly as a more or less uniform but discontinuous sheet, and partly as irregular hillocks and ridges strewn with erratic

Finnish Geological Survey ("Bidrag till Kännedomen om södra Finlands kvartära Nivåförändringar," Helsingsfors, 1896). He shows how from zero at St. Petersburg the depression progressively increased towards the north-west.

[1] There is now an ample though recent literature devoted to the glacial phenomena of Germany. The volumes of the *Zeitsch. Deutsch. Geol. Gesellschaft* for 1879 and subsequent years contain papers by G. Berendt, H. Credner, J. E. Geinitz, A. Helland, K. Keilhack, F. Noetling, A. Penck, R. Richter, F. Wahnschaffe, F. Schmidt, &c. See also the *Jahrb. Preuss. Geol. Landesanstalt* for 1880 and following years; the Maps and Explanations of the same Survey for the neighbourhood of Berlin (27 sheets) and the memoirs of the Geological Survey of Saxony. The work of Dr. Keilhack is specially worthy of the attention of the student, particularly the papers in *Jahrb. Preuss. Geol. Landesanst.* from 1889 onwards.

[2] G. Berendt, *Jahrb. Preuss. Geol. Landesanst.* 1888, p. 110; K. Keilhack, *op. cit.* 1889, p. 149.

[3] Dr. Keilhack has traced what he believes to be five distinct stages in the backward shrinkage of the ice during the last of the three glacial epochs into which he divides the whole Ice Age, *Jahrb. Preuss. Geol. Landesanst.* 1898, p. 90. The end-moraines of Schleswig Holstein are described by C. Gottsche, *Mitth. Geograph. Ges. Hamburg*, xiii. xiv. (1897-98), who gives lists of the shells from the marine diluvium.

[4] A. G. Nathorst, *Öfver. Vet. Akad. Förhandl. Stockholm*, 1894.

blocks, and enclosing pools of water and peat-bogs. These mounds and ridges, with their accompanying sheets of water, form a conspicuous feature of the low tract of country from Schleswig Holstein [1] eastwards to the Vistula.

In some of the mountain groups of Germany there is evidence that probably at the height of the Ice Age glaciers existed. Reference has already been made to the moraine mounds of the Vosges [2] and Black Forest,[3] and to the fact that the glaciers of the western hill-groups were more extensive than those to the east. In the Carpathian range, a series of moraines, sometimes enclosing lakes, is distributed in the valleys that radiate from the Hohe Tatra.[4] On both sides of the Riesengebirge, moraines occur. At the sources of the Lomnitz, on the southern side, they enclose two lakes at the foot of high recesses and cliffs.[5] No certain traces of glaciers appear to have been met with in the eastern part of the Sudeten range, nor in the Erzgebirge or Thuringerwald. Farther north, in the Harz, mounds of detritus which resemble moraines have been referred by Kayser to glacier-action.[6] The German Alps and the Bavarian plateau bear witness to the former greater extent of the still remaining glaciers, and to the spread of the ice across wide tracts from which it has long retreated.[7] The chain of the Carpathians was likewise a distinct glacier centre.[8]

France, Pyrenees.—As France lay to the south of the northern ice-sheet, the true till or boulder-clay is there absent, as it is for the same reason from the south of England. It is consequently difficult to decide which superficial accumulations are really contemporary with those termed older glacial farther north, and which ought to be grouped as of later date. The ordinary sedimentation in the non-glaciated area not having been interrupted by the invasion of the ice-sheet, deposits of pre-glacial, glacial, and post-glacial time naturally pass insensibly into each other. The older Pleistocene deposits (perhaps interglacial) consist of fluviatile gravels and clays which, in their composition, belong to the drainage systems in which they occur. There is generally no evidence of transport from a great distance, though, in the Champ de Mars at Paris, blocks of sandstone and conglomerate nearly a yard long sometimes occur, as well as small pieces of the granulite of the Morvan. Erratics at Calais and on the coast of Britanny may also have been carried a long way.[9] The rivers, however, were probably much larger during some part of the Pleistocene period than they now are, and the transport of their stones may have been sometimes effected by floating ice, as has been forcibly shown by Professor Barrois in reference to the old gravels of Brittany.[10] They have left their ancient platforms of alluvium in successive terraces high above the present watercourses. Each terrace consists generally of the following succession of deposits in ascending order :—(1) A lower gravel (*gravier de fond*), the pebbles of which are coarsest towards the bottom and are interstratified with layers of sand, sometimes

[1] The glacial phenomena of Denmark and Schleswig Holstein are discussed by Gottsche in the series of papers cited above ; by V. Madsen in the Explanatory Memoirs to accompany the sheets of the Geological Survey map of Denmark. The Jurassic, Neocomian and Gault boulders found in Denmark are discussed by Miss Skeat and V. Madsen in No. 8 of the second series of these Explanations (1898).

[2] H. Hogard, 'Terrain erratique des Vosges,' 1851. A. Delebecque, "Système glaciaire des Vosges Françaises," *Bull. Carte Géol. France*, No. 79 (1901).

[3] J. Partsch, 'Gletscher der Vorzeit in der Karpathen und der Mittelgebirgen Deutschlands,' Breslau, 1882, p. 115.

[4] Partsch, *op. cit.* p. 9.

[5] *Ibid.* p. 55.

[6] Lossen and Kayser, *Z. D. G. G.* xxxiii. (1881).

[7] A. Penck, 'Vergletscherung der Deutschen Alpen,' 1882.

[8] J. Partsch, 'Die Gletscher der Vorzeit.'

[9] Ch. Velain, *Bull. Soc. Géol. France*, xiv. (1886), p. 569

[10] *Ann. Soc. Géol. Nord*, iv. (1877), p. 186.

inclined and contorted. (2) Grey sandy loam (*sable gras*). (3) The foregoing strata are covered by yellow calcareous loess, or with an overlying dark brown loam or brick-earth. The upper exposed parts of the gravels and sands are commonly well oxidised, and present a yellowish-brown or deep reddish-brown tint, while the lower portions remain more or less grey. Hence the old names *diluvium gris* and *diluvium rouge*. The gravels and brick-earths have yielded terrestrial and fresh-water shells, most of which are of still living species, and numerous mammalian bones, among which are *Rhinoceros antiquitatis* (*tichorhinus*), *R. etruscus*, *R. leptorhinus*, *Hippopotamus amphibius*, *Elephas antiquus*, *E. primigenius*, wild boar, stag, roe, ibex, Canadian elk, musk-sheep, urus, beaver, cave-bear, wolf, fox, cave-hyæna, and cave-lion. Palæolithic implements found in the same deposits show that man was a contemporary of these animals (see p. 1355).[1] Even as far south as Charente from fissures in a Cretaceous limestone remains of a fauna with northern species have been obtained, including *Arctomys marmotta*, *Spermophilus rufescens*, *Lepus variabilis*, *Microtus* (*Arvicola*) *amphibius*, *M. ratticeps*, *Canis vulpes*, *C. lagopus*, *C. lupus*, *Hyæna crocuta*, *Mustela pitorius*, *Felis leo* (*spelæa*), *Equus caballus*, *Bison priscus* (?), and *Rangifer* (*Cervus*) *tarandus*.[2] In the south-west of France the arctic fox has also been obtained, together with the musk-sheep.

It is in the centre and east of France that the most unequivocal signs of the ice of the Glacial Period are to be met with. The mountain groups of Auvergne, which even now show deep rifts of snow in summer, had their glaciers whereby the solid rocks were smoothed, polished and striated, and moraine heaps with large blocks of rock were strewn over the valleys; not only so, but there is evidence in that region of a retreat and redescent of the ice, for above the older moraines lie interglacial deposits containing abundant remains of land-plants, with bones of *Elephas meridionalis*, *Rhinoceros leptorhinus*, &c., the whole being covered by newer moraines.[3]

The much lower grounds of the Lyonnais and Beaujolais (rising to more than 3000 feet) likewise supported independent snowfields.[4] The glacier of the Rhone and its tributaries at the time of the maximum glaciation was so gigantic as to fill up the hollow of the Lake of Geneva and the vast plain between the Bernese Oberland and the Jura. It crossed the Jura and advanced to near Besançon. It swept down the valley below Geneva, and then, joined by its tributaries, spread out over the lower hills and plains until the whole region from Bourg to Grenoble was buried under ice. The evidence of this great extension is furnished by rock-striæ, transported blocks, and moraine stuff.[5]

The chain of the Pyrenees nourished along its whole length an important tract of snowfield, whence glaciers descended all the main valleys and there shed their moraines.[6] The phenomena are quite comparable to those of the Alps or the more northerly groups of mountains. It would appear that even as far south as the Serra da Estrella of

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[1] A detailed study of the Quaternary deposits of the north of France has been made by J. Ladrière, who divides them into three stages, each marked off by a gravelly layer at the base and terminating above in a loam with terrestrial vegetation and fresh-water and terrestrial shells. The lowest is the assise with *Elephas primigenius* and *Rhinoceros tichorhinus*, *Ann. Soc. Géol. Nord*, xviii. (1890), p. 93.

[2] M. Boule and G. Chauvet, *Compt. rend.* May 1899.

[3] Julien, 'Des Phénomènes glaciaires dans le Plateau central de la France,' 1869; Rames, *B. S. G. F.* 1884. A clear summary of the glaciation of Auvergne is given by M. Boule in the *Annales de Géographie*, 15th April 1896.

[4] Falsan and Chantre, 'Anciens Glaciers,' ii. p. 384.

[5] Falsan and Chantre, *op. cit.*

[6] See the account given by Dr. Penck in the *Mitt. Ver. Erdkunde Leipzig*, 1883, with a bibliography up to that date.

Portugal, which in lat. 40·15 N. rises to a height of more than 6000 feet, glaciers existed and produced their striated rocks, moraines, and erratic blocks.[1]

Belgium.—The Quaternary deposits of this country, like those of Northern France, belong to a former condition of the present river-basins. In the higher tracts, they are confined to the valleys, but over the plains they spread as more or less continuous sheets. Thus, in the valley of the Meuse, the gravel-terraces of older diluvium on either side bear witness only to transport within the drainage-basin of the river, though fragments of the rocks of the far Vosges may be detected in them. The gravels are stratified, and are generally accompanied by an upper sandy clay. In middle Belgium, the lower diluvial gravels are covered by a yellow loam (Hesbayan), probably a continuation of the German loess, with numerous terrestrial shells (*Succinea oblonga*, *Pupa muscorum*, *Helix* [*Hygromia*] *hispida*). In lower Belgium, this loam is replaced by the Campinian sands, which have been observed lying upon it. The Belgian caverns and some parts of the diluvium have yielded a large number of mammalian remains, among which there is the same commingling of types from cold and from warm latitudes so observable in the Pleistocene beds of England and France. Thus the Arctic reindeer and glutton are found with the Alpine chamois and marmot, and with the lion and grizzly bear.

The **Alps.**[2]—Reference has already been made to the vast extension of the Alpine glaciers during the Ice Age. Evidence of this extension is to be seen both among the mountains and far out into the surrounding regions. On the sides of the great valleys, ice-striated surfaces and transported blocks are found at such heights as to show that the ice must have been in some places 3000 or 4000 feet thicker than it now is. The glacier of the Aar, for instance, which was a comparatively short one, being turned aside by and merging into the large stream of the Rhone glacier near Berne, attained such dimensions as not only to fill up the valley now occupied by the Lakes of Thun and Brienz, but to override the surrounding hills. The marks made by it are found at a height of 930 metres above the valley, which with 305 metres for the depth of Lake Brienz, gives a thickness of at least 1235 metres or 4000 feet of ice moving down that valley. Judging from the evidence of the heights of the stranded blocks, the slope of this glacier varied from 45 in 1000 in its upper parts to not more than 2 in 1000 towards its termination.[3] From the variation in the direction of the striæ, as well as in the distribution of the transported blocks, there can be little doubt that the Alpine glaciers varied from time to time in relative dimensions, so that there was a kind of struggle between them, one pushing aside another, and again being pushed aside in its turn.

Turning to the regions beyond the mountains, we find that proofs of glaciation reach to almost incredible distances. The Rhone glacier has already been referred to as overwhelming the mountainous and hilly intervening country, and throwing down its moraines with blocks of the characteristic rocks of the Valais where Lyons now stands, that is,

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[1] J. F. Nery Delgado, *Comm. Direc. Trabal. Geol.* iii. Fasc. i. (1895).

[2] Besides the works of Falsan and Chantre, Penck and Partsch, above cited, the student may consult Morlot, *Bib. Univ.* 1855; *Bull. Soc. Vaud. Sci. Nat.* 1858, 1860. Heer, 'Urwelt der Schweiz.' The map of the ancient glaciers of the north side of the Swiss Alps, published in four sheets by A. Favre, Geneva, 1884. C. W. Gümbel, *Sitzb. Akad. Wien*, 1872. R. Lepsius, 'Das westliche Süd-Tirol,' Berlin, 1878. A. Heim, 'Handbuch der Gletscherkunde,' 1885. Baltzer, *Mittheil. Naturf. Ges.* Berne, 1887, "Der Diluviale Aargletscher," *Beiträg. Geol. Kart. Schweiz.* Lief. 30, 1896. Aeppli, *op. cit.* Lief. 34. Renevier, *Bull. Soc. Helv.* 1887. A. Böhm, *Jahrb. k. k. Geol. Reichsanst.* xxxv. (1885), p. 429. A. Penck, E. Brückner, and L. du Pasquier, in their memoir already cited on p. 1301, which was published as a guide to the glaciation of the region during the meeting of the International Geological Congress at Zurich in 1894.

[3] A. Favre, *Arch. Ann. Sci. Phys. Nat. Genève*, xii. 1884.

170 miles in direct distance from where the present glacier ends. The same ice-sheet, swelled from the northern side of the Bernese Oberland, overflowed the lower ridges of the Jura, streaming through the transverse valleys, even as far as Ornans near Besançon. Turning north-eastward, it filled up the great valley of Switzerland, and, swollen by the tributary glaciers of the Aar, the Reuss, and the Linth, joined the vast stream of the Rhine glacier above Basle. The enormous *mer de glace* poured over the Black Forest and down the valley of the Danube at least as far as Sigmaringen, where blocks of the rocks of the Grisons occur. Eastward it was joined by the great glacier that descended from the Swabian and Bavarian Alps, and of which the moraine-heaps are strewn over the lowlands as far as Munich. The Tyrolese and Carinthian Alps were likewise buried under an icy covering which sent a huge glacier eastwards down the valley of the Drau. On the south side of the Alps, the glaciers advanced for some way out into the plains of Lombardy, where they threw down enormous moraines, which sometimes reach a height of more than 2000 feet (Ivrea). These vast accumulations, to which there is no parallel elsewhere in Europe, rise into conspicuous hills and crescent-shaped ridges round the lower ends of the upper Italian lakes. At some of these localities the moraine stuff rests on marine Pliocene beds. It is possible that the glaciers actually reached the sea-level.[1] There appears to be no doubt, at least, that they descended to a lower level on that side than on the northern side of the Alps.

By tracing the distribution of the transported blocks, the movements of the ancient glaciers can be satisfactorily followed. These blocks are not dispersed at random over the glaciated area. Each glacier carried the blocks of its own basin, and, where these are of a peculiar kind, they serve as an excellent guide in following the march of the ice. Not only were the blocks in each drainage area kept separate from those of adjoining basins, but those on the left sides of the valleys do not, except along the junction lines, mingle with those of the right sides. As a rule, the blocks lie along the slopes of the valleys rather than on the bottoms, and are often disposed there in groups or lines. In the Arve valley, near Sallanches, for example, a zone comprising several thousand granitic boulders runs for a distance of more than three miles. The blocks of Monthey have long been famous. On the flanks of the Jura near Solothurn, the boulders of Riedholz, stranded there by the ancient Rhone glacier, still number 228, though they have been reduced by the quarrying operations, now happily interdicted (see Figs. 160, 161, 162).[2]

That the Ice Age in the Alps, as in Northern Europe, was interrupted by at least one warmer interglacial period, when the ice retreating from the valleys allowed an abundant vegetation to flourish there, is shown by the lignites of Durnten (Canton Zurich), Utznach (St. Gall), Hötting (near Innspruck), and several other places. These deposits can here and there be seen to overlie ancient moraine stuff; they are interstratified with fluviatile gravels and sands, which again are surmounted with scattered erratic blocks belonging to a later period of glaciation. Among these interglacial vegetable accumulations Heer recognised several pines and firs (*Pinus abies*, *P. sylvestris*, *P. montana*), larch, yew, oak, sycamore, hazel, mosses, bog-bean, bulrush, raspberry, and *Galium palustre*, as well as bog-mosses, all still growing in the surrounding country. With the plants there occur the remains of *Elephas*, *Rhinoceros etruscus*, *Bos taurus*, var. *primigenius* or urus, red-deer, cave-bear, likewise traces of fresh-water shells and insects, chiefly elytra of beetles.

The succession of main events in the history of the Ice Age in Switzerland have been tabulated as follows:[3]—

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[1] The surface of the Lago di Garda, round the lower end of which glacier moraines extend, is little more than 200 feet above the sea-level.

[2] Favre, *Arch. Sci. Phys. Nat. Genève*, xii. (1884), p. 399.

[3] Penck ('Vergletscherung der Deutschen Alpen') believes that evidence can be traced of at least three distinct periods of glaciation in the Alps. Heer, 'Urwelt der Schweiz';

Post-glacial. Ancient lacustrine terraces (150 feet above present level of Lake of Geneva), deltas, and river gravels with *Limnæa stagnalis*, and other fresh-water shells, bones of mammoth (?). Gradual lowering of the level of the lakes through the cutting down of the moraine barriers.

Third glacial period. Erratic blocks and terminal moraines of Zurich, Baldegg, Sempach, Berne, with an Arctic flora and fauna. Schotter of the lower terraces, and of Utznach, Wangen, Reidbach. Au, Glatthal, Sihlbrugg.

Second interglacial series. Lignites and clays of Utznach, Wangen, Dürnten. Wetzikon, covered by the moraine stuff of the third glaciation and overlying older glacial deposits *Elephas antiquus*, *Rhinoceros megarhinus* (*Merckii*). This interglacial epoch is regarded as having lasted a shorter time than the first.

Second glacial period. Greatest extension of the glaciers; chief accumulation of moraines; deposit of the extramorainic high-terrace schotter.

First interglacial interval, supposed to have continued for a long period of time, during which the last uplift of the molasse on the skirts of the Jura took place; subsidence of the body of the Alps; birth of some lakes, such as those of Zurich and Zug. During this period valleys were eroded in the molasse and progressively deepened while the slopes were terraced.

First glacial period, supposed to be indicated by the deposit of the Decken-schotter.

Russia. A vast extent of Russia was buried under the greatest extension of the ice-sheet, the southward limits of which across the country have already been stated (p. 1305). There appears to be evidence that the second advance of the ice not only affected the western lowlands that were covered by the Baltic glacier, but even the centre of the country. Proofs have been obtained of an interglacial period in Central Russia marked by lacustrine deposits intercalated between glacial clays. They have yielded an abundant flora, including alder, birch, hazel, willow, fir, water-lilies, and remains of mammoth &c.[1] Perhaps the most singular feature of the glacial deposits of Russia is to be found in the sheets of ice which, underlying and interstratified with the clays, have survived as actual fossil remains of the ice-sheets of the Pleistocene ages along the low grounds of the coast-region of Siberia, and in the opposite New Siberian Islands. The ice is sometimes separated from the living vegetation, including larch trees, by a mere thin layer of humus, or is covered with a layer of peat full of well-preserved leaves and fruit of alder (*Alnus fruticosa*). It has been called "stone-ice," "dead-ice," "fossil-glacier," and has been clearly made out to form a sheet of variable thickness resting on a ground-moraine and covered by fluviatile or lacustrine strata of clay and sand, which in their lower parts are sometimes interleaved with thin laminæ of ice or are permeated by ice and solidly frozen. In some places the ice ends at the coast in a lofty vertical cliff, with the thin layer of soil or peat and living Arctic vegetation on the summit. From the frozen sedimentary deposits that overlie the ice, carcases of the mammoth and *Rhinoceros megarhinus* (*Merckii*) have been obtained, sometimes with the flesh, skin and hair still perfectly preserved. The same strata have yielded shells of *Sphaerium*, *Valvata*, *Pisidium*, larvæ of *Phryganea* and remains of Arctic birch (*Betula nana*) and species of willow. The large mammals appear to have perished, owing perhaps to some general change of climate, and their bodies when immersed in the silt of lakes or rivers were eventually frozen there, and so have remained till the present time. The musk-sheep and reindeer, which were their contemporaries, were more fortunate in withstanding the unfavourable meteorological conditions, and still survive in the Arctic regions.[2]

A. Aeppli, "Erosionsterrassen und Glazialschotter in ihrer Beziehung zur Entstehung des Zurichsees," *Beiträg. Geol. Kart. Schweiz*, Lief. 34 (1894), p. 116.

[1] N. Krischtafowitsch, *Bull. Soc. Imp. Nat. Moscou*, No. 4 (1890); *Ann. Géol. Min. de la Russie*, Warsau, 1896. On glaciation of Urals see Nikitin, *Neues Jahrb.* i. (1888), p. 172. Fraulein A. Missuna describes two bands of end-moraines in the departments of Wilna, Witebsk, and Minsk, *Z. D. G. G.* 1902, p. 284.

[2] For a detailed history of the investigation of the Siberian ice-cliffs and their organic remains, with a narrative of personal exploration of them, see the able and interesting memoir

Africa.—An interesting proof of a former greater extent of the existing glaciers is furnished by Mount Kenya, which in British East Africa rises almost on the equator to a height of about 19,500 feet above the sea, and covers an area of about 700 square miles. Some 5400 feet below the limits to which the glaciers have now retreated they have left moraines, rock-striæ, perched blocks and glacial lake basins, and these are on such a scale as to indicate that they were produced not by mere valley-glaciers but by an ice-cap that covered the whole mountain. Professor Gregory, whose observations made known these features, believes that the glaciation was due to a former greater elevation of Mount Kenya, which has been reduced by subsidence and denudation, there being no evidence of any universal glaciation of the region.[1]

North America.[2]—The general succession of geological changes in Post-Tertiary time appears to have been broadly the same all over the northern hemisphere. In North America, as in Europe, there is a glaciated and non-glaciated area; but the line of demarcation between them has been much more clearly traced on the western side of the Atlantic. The glaciated area extending over Canada and the north-eastern States presents the same characteristic features as in the Old World. The rocks, where they could receive and retain the ice-markings, are well-smoothed and striated. The direction of the striæ is generally southward, varying to south-east and south-west according to the form of the ground. The great thickness of the ice-sheet is strikingly shown by the height to which some of the higher elevations are polished and striated. Thus the Catskill Mountains, rising from the broad plain of the Hudson, have been ground smooth and striated up to near their summits, or about 3000 feet, so that the ice must have been of even greater thickness than that. The White Mountains are ice-worn even at a height of 5500 feet. G. M. Dawson has found glaciated surfaces in British Columbia 7000 feet above the sea.[3]

On detailed examination of the rock-striation it has been found that the ice probably had its origin mostly if not entirely on the continent itself, and that it radiated from certain areas of maximum accumulation of snow. Of these areas there appear to have been at least three in the north of British America. The most easterly, known as the Laurentide ice-sheet, covered the wide peninsula between the depression of Hudson Bay and the Labrador coast, and streamed southward across the basin of the St. Lawrence and the north-eastern States into Pennsylvania and as far west as the valley of the Mississippi. A second centre of dispersion, which gave rise to what has been called the Keewatin ice-sheet, lay to the west of the Hudson Bay hollow, whence the ice radiated in all directions. On the north side it moved towards the Arctic Ocean, on the east it descended into the low ground till it joined the Laurentide sheet and moved southward to shed its terminal moraine in Iowa and Dakota. The third centre lay far to the west in the Canadian portion of the lofty Cordillera of the Rocky Mountains, and gave birth to a vast ice-sheet which moved westward down the steeper slope into the Pacific and south-

of Baron E. von Toll in *Mem. Akad. Imp. St. Petersbourg*, xlii. (1895), No. 13; also A. G. Nathorst, *Ymer*, 1896, p. 79.

[1] *Q. J. G. S.* l. (1894), p. 515.

[2] See J. D. Whitney, "Climatic Changes of later Geological Times," *Mem. Mus. Compar. Zool. Harvard*, vol. vii. 1882; and papers by J. D. Dana, T. C. Chamberlin, R. D. Salisbury, W. Upham, George M. Dawson, H. Carvill Lewis, G. F. Wright, S. Calvin, I. C. Russell, B. K. Emerson, J. B. Tyrrell, H. L. Fairchild, R. S. Tarr, F. Leverett, and others in *Amer. Journ. Sci.*, *American Geologist*, *Journal of Geology*, *Canadian Naturalist*, *Canadian Journal*, *Ann. Reports*, *Bulletins and Monographs of U.S. Geol. Survey*; *Geol. Surv. New Jersey*; *Second Geol. Surv. of Pennsylvania*; *Reports of the Canadian Geol. Survey*; J. W. Dawson, 'Acadian Geology,' 1878; 'Handbook of Canadian Geology,' 1889; 'The Canadian Ice Age,' 1893; G. M. Dawson, *Trans. Roy. Soc. Canada*, viii. sect. iv. (1890), p. 25; G. F. Wright, 'Man and the Glacial Period,' 'The Ice Age in America.'

[3] *Geol. Mag.* 1889, p. 351; see also W. Upham, *Appalachia*, v. (1889), p. 291.

eastward into the high inland plateaux. Besides these great *mers de glace* there were minor glacier centres among the higher mountain groups farther south.

As in Europe, the glacial deposits increase in thickness and variety from south to north, spreading across Canada, over a considerable area of the north-eastern States, and rising to a height of 5800 feet among the White Mountains. From the evidence of the rock-striæ and the dispersion of boulders, it has been ascertained that, though the glaciated region was probably buried under one deep continuous *mer de glace* like that of Greenland at the present time, there were considerable variations in the direction of motion, owing partly to the individual movements of the several ice-sheets and partly to inequalities in the general slope of the ground underneath. Nothing, however, is more striking than the apparent indifference with which the ice streamed onward, undeflected even by considerable ridges and hills. The line of the southern margin of the ice can still be followed by tracing the limits to which the drift deposits extend southwards. From this evidence we learn that the ice-sheet ended off in a sinuous line, protruding in great tongues or promontories and retiring into deep and wide bays. In the eastern States, the southern limit of the glaciated region is marked by one of the most extraordinary glacial accumulations yet known, and to which in Europe there is no rival. It consists of a broad irregular band of confused heaps of drift, or more strictly of two such bands, which sometimes unite into one broad belt and sometimes separate wide enough to allow an interval of twenty or thirty miles between them, each being from one to six miles in breadth and rising several hundred feet above the surrounding country. The surface of these ridges presents a characteristic hummocky aspect, rising into cones, domes, and confluent ridges, and sinking into basin-shaped or other irregularly-formed depressions, like the kames or ösar of Europe. The upper part of the material composing the ridges generally consists of assorted and stratified gravel and sand, the stratification being irregular and discordant, but inclined on the whole towards the south. Below these rearranged materials is a boulder-drift—a mixture of clay, sand, and gravel, with boulders of all sizes, up to blocks many tons in weight and often striated. Though sometimes indistinguishable from ordinary till, it presents as a rule a greater preponderance of stones than in typical till, but contains also fine stratified intercalations. A large proportion of the material of the ridges has been derived from rocks lying immediately to the north, and the nature of the ingredients constantly varies with the changing geological structure of the ground. There is also always present a greater or less amount of detritus representing rocks along the line of drift-movement for 500 miles or more to the north. The band of drift-hills lies sometimes on an ascending, sometimes on a descending slope, crosses narrow mountain ridges and forms embankments across valleys, showing such a disregard of the topography as to prove that it cannot have been a shore-line, and has not been laid down with reference to the present drainage system of the land.[1]

To this remarkable belt of prominent hummocky ground the name of "terminal moraine" has been given by the American geologists who have so successfully traced its distribution and investigated its structure. The conditions, however, under which the drift rampart in question was formed certainly differed widely from those that determine an ordinary terminal moraine. The constituent materials can hardly have travelled on the surface of the ice, but must rather have lain underneath it or have been pushed forward in front of it. But the mode of formation is a problem which, though recent observations in Greenland and Spitzbergen (p. 544) have thrown light on it, cannot be said to have as yet been wholly solved.

There seems good reason to believe that there are at least two "terminal moraines" belonging to two distinct and perhaps widely separated epochs in the Ice Age. The

[1] H. C. Lewis, "Report on the Terminal Moraine," *Second Geol. Surv. Pennsylvania*, Z, 1884, p. 45, with Preface by J. P. Lesley.

most southerly and therefore oldest of them begins on the Atlantic border off the south-eastern coast of Massachusetts, where it is partially submerged. Rising above the level of the sea in Nantucket Islands, Martha's Vineyard, No Man's Island, and Black Island, it is prolonged into Long Island, of which it forms the back-bone, and where it reaches heights of 200 to nearly 400 feet. A second or later and less prominent line of drift-hills runs along the north shore of Long Island, and is prolonged by Fisher's Island into the southern edge of the State of Rhode Island, whence, striking out again to sea, it forms the chain of the Elizabeth Islands, passes thence into the State of Massachusetts, and runs nearly east and west through the peninsula of Cape Cod. The distance between these two bands of hummocky ridge varies from five to thirty miles. From the western end of Long Island the moraine passes across Staaten Island and the northern part of New Jersey, enters Pennsylvania a little north of Easton, and follows a sinuous north-westerly course across that State and for some miles into the State of New York, where, forming a deep indentation, it wheels round in a south-westerly direction, re-enters Pennsylvania, and passes into Ohio. Throughout this long line, the moraine coincides with the southern limit of the drift and of rock-striation, though in western Pennsylvania, in front of the ridge, scattered northern boulders are found over a strip of ground which gradually increases south-westwards to a breadth of five miles.[1] Beyond Central Ohio, however, the drift extends far to the south. Taking its limits as probably marking the extreme boundary of the ice-sheet (then at its largest), we find that it goes southwards, perhaps nearly as far as the junction of the Ohio with the Mississippi, sweeping westwards into Kansas, and then probably turning northwards through Nebraska and Dakota, but keeping to the west of the Missouri River.

The inner or second terminal moraine is characteristically developed in the southern part of the State of New York, lying well to the north of the first moraine, and much more irregularly distributed. South-westwards the two series of ramparts unite at the sharp bend of the older ridge just mentioned, and continue as one into the centre of Ohio. This junction probably indicates that the southern edge of the ice at the time of the second moraine, though generally keeping to the north of its previous limit, reached its former extent in north-western Pennsylvania, and united its débris with that left at the time of the greatest extension of the ice-sheet. From the middle of Ohio, the younger moraine pursues an extraordinarily sinuous course. One of its most remarkable bends encloses the southern half of Lake Michigan, which was the bed of a great tongue of ice moving from the north. Immediately to the west of this loop there lies an extensive driftless area in Wisconsin and Minnesota. The course of the moraine bears distinct witness to the independent direction of flow of the united glaciers that constituted the great ice-sheet. It sweeps in vast indentations and promontories across Wisconsin, Minnesota, and Iowa, forming probably the most extensive moraine in the world, and strikes north-westward through Dakota for at least 400 miles into the British Possessions, where its further course has been partially traced. The known portion of the moraine thus extends with a wonderful persistence of character for 3000 miles, reaching across two-thirds of the breadth of the continent.[2] Much attention has been paid to the variations in the nature of the drifts in the intra-morainic and extra-morainic areas, as evidence of the various advances and retreats of the ice.[3]

[1] In this strip of ground, called by Lewis the "fringe," though there are no rock-striæ or drift, scattered northern boulders occur. *Op. cit.* p. 201.

[2] T. C. Chamberlin, "Preliminary Paper on the Terminal Moraine," *3rd Ann. Rep. U.S. G. S.* 1883. Every student of glacial geology ought to make himself familiar with this admirable summary. Consult also G. M. Dawson, 'Report on 49th Parallel'; F. Wahnschaffe, *Z. D. G. G.* 1892, p. 107. J. B. Tyrrell (*Bull. Geol. Soc. Amer.* i. (1890), p. 395) describes the terminal moraines in Manitoba and the adjacent territories of N.W. Canada.

[3] See in particular the *Reports and Maps of the Geol. Surv. New Jersey*, by R. D. Salisbury and his colleagues.

In the non-glaciated regions, evidence of the presence and influence of the ice-sheet is probably furnished by high alluvial terraces, which could not have been formed under the present conditions of drainage. From this kind of evidence it is believed that when the ice-sheet crossed the Ohio River near Cincinnati, it ponded back the drainage of the entire water-basin of East Kentucky, south-east Ohio, West Virginia, and Western Pennsylvania, up to a height of perhaps 1000 feet, forming a lake at that level.[1] Similar indications of a lake, caused by an ice-dam ponding back the drainage, are found at the head of the Red River in Minnesota.[2] The largest sheet of fresh water which has left its records in that region has been called "Lake Agassiz." It occupied the basin of the Red River of the North and Lake Winnipeg, and appears to have been due to the interception of the drainage northward by the united Keewatin and Laurentide ice-sheets. It is computed to have been 700 miles long from north to south, and to have covered, from first to last, an area of 110,000 square miles, thus exceeding the total area of the five great existing lakes—Superior (31,200), Michigan (22,450), Huron with Georgian Bay (23,800), Erie (9960), Ontario (7240), which have a united area of 94,650 square miles.[3] Many other "glacial lakes," which no longer exist because their ice-barriers have disappeared, have been found scattered over Canada.[4]

The deposits left by the ice-sheet within the limits of the terminal moraines so resemble those of Europe that no special description of them is required. The lowest of them, resting on ice-worn rocks, is a stiff, unstratified boulder-drift or till, full of polished and striated stones. Occasional "interglacial" intercalations of sand and clay, which in some places, as at Portland, in Maine, have yielded many existing species of marine organisms, and in others, as in Iowa, include forest-beds, peat and other remains of land-plants, with fresh-water shells, separate the lower from an upper boulder clay, which is looser, and more gravelly and sandy than the older deposit, contains larger rough and angular blocks, and has acquired a yellow tint from the oxidising influence of surface waters.[5] The boulders vary up to 10 feet (sometimes even 40 feet) in diameter, and have seldom travelled more than 20 miles. The boulder-clays over wide areas are distributed in lenticular ridges, drums, or drumlins, from a few hundred feet to a mile in length, from 25 to 200 feet high, and with a persistent smoothness of outline and rounded tops.[6] As in Europe, the longer axes of these drums is generally parallel with that of the striation of the underlying rocks.

At the height of the Ice Age there were large glaciers in the Rocky Mountains of the United States, whereof the small glaciers first found by Hayden's Survey among the Wind River Mountains in Wyoming are some of the last lingering relics.[7] But though the ice filled up the valleys to a depth of 1600 feet or more, and transported vast quantities of detritus which now remains in prominent moraines and scattered boulders,

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[1] H. C. Lewis, "Report on the Terminal Moraine," above cited.

[2] W. Upham, *Proc. Amer. Assoc.* xxxii. (1883), p. 214.

[3] For a full account of this vanished lake (now represented only by scattered sheets of water in the hollows of its basin), with its terraces, dunes, deltas, and other features, see W. Upham's elaborate and instructive monograph, 'The Glacial Lake Agassiz'—a thick quarto volume with numerous maps forming Monograph xxv. of the *U.S. G. S.* 1895.

[4] W. Upham, *Bull. Geol. Soc. Amer.* ii. (1891), p. 243. The vanished Lakes Bonneville and Lahontan (p. 524) are other colossal examples which, though they did not owe their origin to ice-dams, but to an increased rainfall, belong to Quaternary time, and may have been coeval with some of the times of heavier snowfall and greater advance of the ice-sheets.

[5] On the evidence of old soils between the boulder clays see F. Leverett, *Journ. Geol.* vi. (1898), pp. 171, 238; and 'Interglacial Deposits in Iowa,' by Calvin, Leverett, H. F. Bain and J. A. Udden, *Proc. Iowa Acad. Sci.* v. 1898.

[6] W. Upham, *Proc. Bost. Soc. Nat. Hist.* xxiv. (1889), p. 258. See on Till, W. O. Crosby, *op. cit.* xxv. (1890), p. 115. *Technological Quarterly*, ix. (1896), p. 116.

[7] F. V. Hayden's Twelfth Report, *U.S. Geol. and Geog. Survey of the Territories.*

it never advanced into the plateau of the prairie country to the east. Whether or not the glaciers at the north end of the Rocky Mountains merged into and were turned aside by the southward-moving ice-sheet has still to be ascertained. Even far to the west, the Sierra Nevada nourished an important group of glaciers.[1]

The loose deposits or drifts overlying the lower unstratified boulder-clay belong to the period of the melting of the great ice-sheets, when large bodies of water, discharged across the land, levelled down the heaps of detritus that had formed below or in the under part of the ice. There may have been many advances and retreats of the ice-sheets, and the deposits of many successive intervals may be included in the detrital accumulations that have been left behind. Various attempts have been made to unravel the sequence of deposition, but it may be doubted whether any local order which may be ascertained will afford a satisfactory and generally applicable arrangement. The re-modelled drift has by some writers been classed as the "Champlain group."[2] Lower portions are sometimes unstratified or very rudely stratified, while the upper parts are more or less perfectly stratified. Towards the eastern coasts, and along the valleys penetrating from the sea into the land, these stratified beds are of marine origin, and prove that during the "Champlain" period there was a depression of the eastern part of Canada and the United States beneath the sea. The marine accumulations formed during this submergence are well developed in Eastern Canada, where they show the following subdivisions:—

Post-glacial accumulations.
Saxicava sand and gravel, often with transported boulders (Upper Boulder deposits, St. Maurice and Sorel Sands). Shallow-water boreal fauna, *Saxicava rugosa*, bones of whales, &c.
Upper Leda clay (and probably "Saugeen clay" of inland); clay and sandy clay with numerous marine shells, which are the same as those now living in the northern part of Gulf of St. Lawrence; also in some districts fresh-water shells and plants.[3]
Lower Leda clay, fine, often laminated, with a few large travelled boulders (probably equivalent to "Erie Clay" of inland; "Champlain Clay," Lower Shell-sand of Beauport); contains *Portlandia arctica*, *Tellina (Macoma) balthica (grœnlandica)*; probably deposited in cold ice-laden water.
Boulder-clay or till; in the Lower St. Lawrence region contains a few Arctic shells, but farther inland is unfossiliferous.
Peaty beds, marking pre-glacial land-surfaces.[4]

The Leda clays rise to a height of 600 feet above the sea. On the banks of the Ottawa, in Gloucester, they contain nodules which have been formed round organic bodies, particularly the fish *Mallotus villosus* or capeling of the Lower St. Lawrence. Sir J. W. Dawson also obtained numerous remains of terrestrial marsh-plants, grasses, carices, mosses, and algæ. This writer states that about 100 species of marine invertebrates have been obtained from the clays of the St. Lawrence valley. All except four or five species in the older part of the deposits are shells of the boreal or Arctic regions of the Atlantic; and about half are found also in the glacial clays of Britain. The great majority are now living in the Gulf of St. Lawrence and on neighbouring coasts, especially off Labrador.[5]

[1] J. Leconte, *Amer. Journ. Sci.* (3) ix. (1875), p. 126. See A. G. *Amer. Naturalist*, 1880, for a paper on the ancient glaciers of the Rocky Mountains.

[2] See J. D. Dana, *Amer. Journ. Sci.* x. (1875), p. 168; xxvi. (1883), xxvii. (1884); Winchell, *op. cit.* xi. (1876), p. 225.

[3] For a list of Canadian Pleistocene plants see Sir W. Dawson and D. P. Penhallow, *Bull. Geol. Soc. Amer.* i. (1890), p. 311.

[4] J. W. Dawson, 'Supplement to 'Acadian Geology,' 1878; *Canadian Naturalist*, vi. (1871); *Geol. Mag.* 1883, p. 111; *Bull. Geog. Soc. Amer.* i. (1890), p. 311.

[5] Dawson, 'Acadian Geology,' p. 76.

Terraces of marine origin occur both on the coast and far inland. On the coast of Maine they appear at heights of 150 to 200 feet, round Lake Champlain at least as high as 300 feet, and at Montreal nearly 500 feet above the present level of the sea.[1] It would appear that the submergence of which these terraces are the records did not affect the extreme eastern part of the land along the coast from Nova Scotia to New York, but that it steadily increased towards the north till it reached perhaps as much as 800 feet north of Montreal.[2] In the absence of organic remains, however, it is not always possible to distinguish between terraces of marine origin marking former sea-margins, and those left by the retirement of rivers and lakes. In the Bay of Fundy evidence has been cited by Dawson to prove subsidence, for he observed there a submerged forest of pine and beech lying 25 feet below high-water mark.[3]

Inland, the stratified parts of the "Champlain group" have been accumulated on the sides of rivers, and present in great perfection the terrace character already (p. 507) described. The successive platforms or terraces mark the diminution of the streams. They may be connected also with an intermittent uprise of the land, and are thus analogous to sea terraces or raised beaches. Each uplift that increased the declivity of the rivers would augment their rate of flow, and consequently their scour, so that they would be unable to reach their old flood-plains. Such evidences of diminution are almost universal among the valleys in the drift-covered parts of North America, as in the similar regions of Europe. Sometime four or five platforms, the highest being 100 feet or more above the present level of the river, may be seen rising above each other, as in the well-known example of the Connecticut Valley.

The terraces are not, however, confined to river-valleys, but may be traced round many lakes. Thus, in the basin of Lake Huron, deposits of fine sand and clay containing fresh-water shells rise to a height of 40 feet or more above the present level of the water, and run back from the shore sometimes for 20 miles. Regular terraces, corresponding to former water-levels of the lake, run for miles along the shores at heights of 120, 150, and 200 feet. Shingle beaches and mounds or ridges, exactly like those now in course of formation along the exposed shores of Lake Huron, can be recognised at heights of 60, 70, and 100 feet. Unfossiliferous terraces occur abundantly on the margin of Lake Superior. At one point mentioned by Logan, no fewer than seven of these ancient beaches occur at intervals up to a height of 331 feet above the present level of the lake.[4] The great abundance of terraces of fluviatile, lacustrine, and marine origin led, as already stated, to the use of the term "Terrace epoch" to designate the time when these remarkable topographical features were produced. The cause of the former higher levels of the water is a difficult problem. In some cases it has doubtless arisen from dams formed by tongues of ice during the retreat of the ice-sheet.

India.—There is abundant evidence that at a late geological period glaciers descended from the southern slopes of the Himalaya Mountains to a height of less than 3000 feet above the present sea-level. Large moraines are found in many valleys of Sikkim and Eastern Nepal between 7000 and 8000 feet, and even down to 5000 feet, above sea-level. In the Western Himalayas perched blocks are found at 3000 feet, and in the Upper Punjaub very large erratics have been observed at still lower elevations. No traces of glaciation have been detected in Southern India. Besides the physical

[1] On terraces of Lake Ontario see *Amer. Journ. Sci.* (3) xxiv. p. 409.

[2] The deformation of the land during this submergence has been traced by De Geer in an interesting paper "On Pleistocene Changes of Level in Eastern North America," *Proc. Boston Soc. Nat. Hist.* xxv. (1892), p. 454, with a map showing the distribution of the isobases or lines of equal deformation.

[3] 'Acadian Geology,' p. 28.

[4] Logan, 'Geology of Canada,' p. 910. Consult also the paper by G. K. Gilbert on "Lake Shores" cited on p. 524, and the various papers on the uplift of this region referred to on p. 387.

evidence of refrigeration, the present facies and distribution of the flora and fauna on the south side of the Himalaya chain suggest the influence of a former cold period.[1]

Australasia.—The present glaciers of New Zealand are confined to the mountains, though in the case of the Fox glacier they reach to within 650 feet of the sea-level. At a comparatively recent geological period, however, they had a much greater extension, for they descended into the plains, and, on the west side of the island, advanced below the present sea-level. Along that coast-line their moraines now reach the sea-margin; huge erratics stand up among the waves, and the surf breaks far outside the shore-line, probably upon a seaward extension of the moraines.

Captain Hutton has pointed out that there is no biological evidence of any general and serious refrigeration of the climate of the region since Tertiary time: the Pliocene and Pleistocene deposits in their molluscan fauna could not have failed to chronicle it had any such serious change of temperature taken place. He believes that the principal part of the sub-tropical flora and fauna of New Zealand was introduced before the Miocene period, and has flourished ever since, and that any serious diminution of the temperature of the islands would have exterminated all but the more cold-loving species of plants and animals. He maintains that the cause of the former greater extension of the glaciers is to be sought in the fact, of which there are other independent proofs, that the land then stood at a far higher level than it does at present, an additional 3000 to 4000 feet being estimated to suffice for restoring the glaciers to their former maximum size. He likewise adduces grounds for believing that the glacier epoch (which he declines to regard as a *glacial* epoch) in New Zealand dates back to a much earlier time than the Ice Age of the northern hemisphere, probably to the Pliocene period.[2]

It has been ascertained by the evidence of moraines, erratic blocks and striated rock-surfaces, that the Australian Alps once nourished a group of glaciers which, with their snow-fields, may have covered an area of 150 square miles. The ice at Mount Kosciusko crept down to within 5200 feet of the present sea-level, while in Victoria what appears to be moraine material descends to 2000 or possibly to 1000 feet above the sea. At the same time the western highlands of Tasmania between the contours of 2000 and 4000 or 5000 feet were buried under snow and ice. In this region, as in New Zealand, the later Tertiary and post-Tertiary formations have furnished no sufficient proof of any refrigeration of the sea.[3]

To the Upper Pliocene and Pleistocene periods are assigned the wide terraced gravel-banks and alluvial flats which occur in the main valleys of Australia, and the great alluvial plains which in some of the colonies form such marked features. These deposits vary up to 300 feet in depth, and are a great storehouse of alluvial gold. They may possibly indicate that a greater rainfall was concerned in their formation than now characterises the same regions. If the glaciers of New Zealand reached the sea, the mountains of Australia nourished snow-fields, and the great Antarctic ice-sheet crept farther north during some part of this cold period, the rainfall may have been so augmented that the rivers spread out far beyond the limits within which they are now confined.

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[1] Medlicott and Blanford, 'Geology of India,' p. 586.

[2] F. W. Hutton, *Australasian Assoc.* Adelaide, 1893, "Report of Committee on Glacial Action in Australasia." See also his 'Geology of Otago,' p. 83, and for a fuller statement of his views on this subject his address on the Origin of the Fauna and Flora of New Zealand, *N. Zealand Journ. Sci.* (1884); and *Proc. Linn. Soc. N.S. Wales*, x. part 3.

[3] T. W. Edgeworth David, *Address to Section C. Australasian Assoc.* Brisbane, 1895; R. M. Johnston, "The Glacier Epoch of Australasia," *Proc. Roy. Soc. Tasmania*, 1893.

Section ii. Recent, Post-glacial, or Human Period.

§ 1. General Characters.

The long succession of Pleistocene ages shaded without abrupt change of any kind into what is termed the Human or Recent Period.[1] The Ice Age, or Glacial Period, may indeed be said still to exist in Europe. The snow-fields and glaciers have disappeared from Britain, France, the Vosges, and the Harz, but they still linger among the Pyrenees, remain in larger mass among the Alps, and spread over wide areas in Northern Scandinavia. This dovetailing or overlapping of geological periods has been the rule from the beginning of time, the apparently abrupt transitions in the geological record being due to imperfections in the chronicle.

The last of the long series of geological periods may be subdivided into subordinate sections as follows:—

Historic, up to the present time.
Prehistoric { Iron, Bronze, and later Stone. / Neolithic. / Palæolithic. }

The Human Period is above all distinguished by the presence and influence of man. It is difficult to determine how far back the limit of the period should be placed. The question has often been asked whether man was coeval with the Ice Age. To give an answer, we must know within what limits the term Ice Age is used, and to what particular country or district the question refers. For it is evident that even to-day man is contemporary with the Ice Age in the Alpine valleys and in Finmark. There can be no doubt that he inhabited Europe after the greatest extension of the ice. He not improbably migrated with the animals that came from warmer climates into this continent during inter glacial conditions. But that he remained when the climate again became cold enough to freeze the rivers and permit an Arctic fauna to roam far south into Europe is proved by the abundance of his flint implements in the thick river-gravels, into which they no doubt often fell through holes in the ice as he was fishing.

The proofs of the existence of man in former geological periods are not to be expected solely or mainly in the occurrence of his own bodily remains, as in the case of other animals. His bones are indeed now and then to be found,[2] but in the vast majority of cases his former

[1] See for general information Lyell's 'Antiquity of Man,' Lubbock's 'Prehistoric Times,' Evans's 'Ancient Stone Implements,' Boyd Dawkins's 'Cave Hunting' and 'Early Man in Britain,' J. Geikie's 'Prehistoric Europe.'

[2] Mr. E. T. Newton has collected the instances where actual human bones of Palæolithic age have been found. Presid. Address, *Proc. Geol. Assoc.* xv. (1898), p. 246. Reference may be made here to a discovery in a volcanic tuff in the island of Java, regarding which much discussion has arisen. Numerous bones of Pleistocene animals had previously been found in the deposit, but in 1891 the roof of a large skull was obtained which was claimed

presence is revealed by the implements he has left behind him, formed of stone, metal, or bone. Many years ago the archaeologists of Denmark, adopting the phraseology of the Latin poets, classified the early traces of man in three great divisions—the Stone Age, Bronze Age, and Iron Age. There can be no doubt that, on the whole, this has been the general order of succession in Europe, where men used stone and bone before they had discovered the use of metal, and learnt how to obtain bronze before they knew anything of the metallurgy of iron. Nevertheless, the use of stone long survived the introduction of bronze and iron. In fact, in European countries where

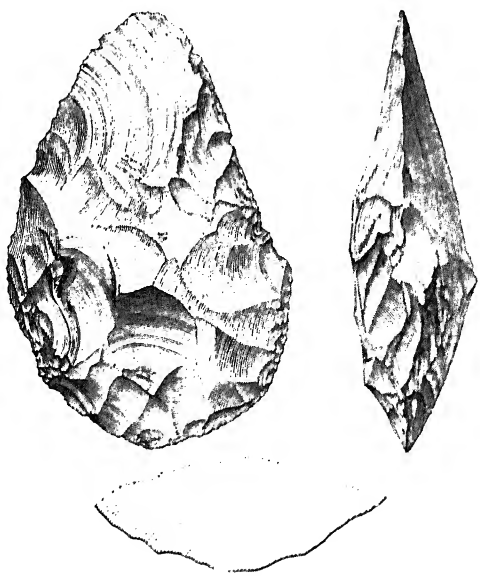

Fig. 495.—Palaeolithic Flint Implement.

metal has been known for many centuries, there are districts where stone implements are still employed, or where they were in use until quite recently. It is obvious also that, as there are still barbarous tribes unacquainted with the fabrication of metal, the Stone Age is not yet extinct in some parts of the world. In this instance, we again see how geological periods run into each other. The material or shape of the implement cannot therefore be always a very satisfactory proof of antiquity. We must judge of it by the circumstances under which it was found. From the fact that in north-western Europe the ruder kinds of stone weapons (Fig. 495) occur in what are certainly the older deposits, while others of more highly finished workmanship (Figs. 498, 499) are

by some as that of an individual intermediate between man and the ape, but by able anatomists is regarded as truly human, though of a low type. Dubois, '*Pithecanthropus erectus*, eine menschenähnliche Uebergangsform aus Java,' Batavia, 1894; D. J. Cunningham, *Nature* li. (1895), p. 428; W. Turner, *op. cit.* p. 621.

found in later accumulations, the Stone Age has been subdivided into an early or Palæolithic and a later or Neolithic epoch. There can be no doubt, however, that the latter was in great measure coeval with the age of bronze, and even, to some extent, with that of iron.[1]

The deposits which contain the history of the Human Period are river-alluvia, brick-earth, cavern-loam, calcareous tufa, loess, lake-bottoms, peat-mosses, sand-dunes, and other superficial accumulations.

PALÆOLITHIC.[2]—Under this term are included those deposits which have yielded rudely-worked flints of human workmanship associated with the remains of mammalia, some of which are extinct, while others no longer live where their remains have been obtained. An association of the same mammalian remains under similar conditions, but without traces of man, may be assigned to the same geological period, and be included in the Palæolithic series. A satisfactory chronological classification of the deposits containing the first relics of man is perhaps unattainable, for these deposits occur in detached areas and offer no means of determining their physical sequence. To assert that a brick-earth is older than a cavern-breccia, because it contains some bones which the latter does not, or fails to show some which the latter does yield, is too often a conclusion drawn because it agrees with preconceptions.

River Alluvia.—Above the present levels of the rivers, there lie platforms or terraces of alluvium, sometimes up to a height of 80 or 100 feet. These deposits are fragments of the river-gravels and loams laid down when the streams flowed at these elevations. The subsequent

[1] The student may profitably consult Sir Arthur Mitchell's 'Past in the Present,' 1880, for the warnings it contains as to the danger of deciding upon the antiquity of an implement merely from its rudeness.

[2] This term has been further subdivided into five minor sections according to the degree of "finish" in the instruments and their presumed chronological order. Thus (1) deposits containing the very rude type of worked flints found at Chelles near Paris, and regarded as the oldest of the series, have been called *Chellean*; (2) those containing flints with evidence of more labour bestowed on them, like the higher type found at St. Acheul, have been termed *Acheulian*; (3) those with implements like the scrapers of Moustier (Dordogne) have been named *Mousterian*; (4) those where the flints have been more deftly worked, like the implements found at Solutré in Burgundy, have been called *Solutrian*; while (5) those which contain well finished implements associated with carved bone and ivory, as at the caves of La Madelaine (Périgord), have been called *Magdalenian* (G. de Mortillet, *Compt. rend. Congrès Géol.* 1878; *Rev. Ecole Anthropologie*, 1897, p. 18. E. Piette, *L'Anthropologie*, vii.). The Magdalenian period or *Glyptic* of Piette has been further divided by him into two great epochs, the *Eburnean* or time of the mammoth, going back into glacial times, when the men lived who carved the likeness of that animal on its tusks, and the *Tarandean* or reindeer epoch, when the climate had ameliorated, but when reindeer still lived in the south of France and were hunted by a more advanced type of mankind (Piette, 'L'époque Eburnéenne,' St. Quentin, 1891; *L'Anthropologie*, vi. vii.). Another classification proposed by Mr. J. Allen Brown is based solely on the character of the implements: (1) Eolithic, (2) Palæolithic, (3) Mesolithic, (4) Neolithic, *Journ. Anthrop. Inst.* 1892. Classifications which do not rest on the evidence of superposition, but merely on the character of human workmanship, must be received with great caution. This basis must often be deceptive and of no chronological value, though some weight may be attached to the presence of different mammals with the different types of instrument.

action of the running water has been to clear out much of the old alluvial material then accumulated, so as to leave the valleys widened and deepened to their present form (*ante*, p. 507). River-action is at the best but slow. To erode the valleys to so great a depth beneath the level of the upper alluvia, must have demanded a period of many centuries. There can therefore be no doubt of the high antiquity of these deposits. They have yielded the remains of many mammals, some of them extinct (*Elephas antiquus*, *Hippopotamus amphibius*, *Rhinoceros megarhinus* (*Merckii*), together with flint-flakes made by man, and even sometimes the bones of man himself.[1] From the nature and structure of some of the high level gravels there can be little doubt that they were formed at a time when the rivers, then possibly larger than now, were liable to be frozen and to be obstructed by accumulations of ice. We are thus able to connect the deposits of the Human Period with some of the later phases of the Ice Age in the west of Europe.

Brick-Earths.—In some regions that have not been below the sea for a long period, a variable accumulation of loam has been formed on the surface from the decomposition of the rocks *in situ*, aided by the drifting of fine particles by wind and the gentle washing action of rain and occasionally of streams. Some of these brick-earths or loams are of high antiquity, for they have been buried under fluviatile deposits which must have been laid down when the rivers flowed far above their present levels. They have yielded traces of man associated with bones of extinct mammals.

Cavern Deposits.—Most calcareous districts abound in underground tunnels and caverns, as well as in fissures opening on the surface of the ground, which have been dissolved by the passage of water from above (p. 477). Where a gaping chasm has communicated with the surface, land animals during successive generations for hundreds of years have fallen into them, until the fissure has been filled up with carcases, and detritus washed in from above.[2] Where, on the other hand, caves have offered places of retreat, they have been used as dens by animals and as dwellings by man himself. The floors of such caverns are not infrequently covered with a reddish or brownish loam or cave-earth, resulting either from the insoluble residue of the rock left behind by the water that formed the caverns by solution, or from the deposit of silt carried by the water, which in some cases has certainly flowed through these passages. Very commonly a deposit of stalagmite has formed from the drip of the roof above the cave-earth. Hence any organic remains which may have found their way to these floors have been sealed up and admirably preserved.

Calcareous Tufas.—The deposits of calcareous springs have sometimes preserved remains of the flora and fauna contemporaneous with the early human inhabitants of a country. In Europe, among the more celebrated of these deposits are those of Cannstadt in Wurtemburg, which

[1] E. T. Newton, 'On a Human Skull and Limb-bones in Palæolithic Gravel, Galley Hill, Kent,' *Q. J. G. S.* li. (1895), p. 505.

[2] For examples see pp. 1094, 1237, 1266, 1358.

have yielded specimens of twenty-nine species of plants, consisting of oaks, poplars, maples, walnuts, and other trees still living in the surrounding country, but with the remains of the extinct mammoth; and of La Celle, near Moret, in the valley of the Seine.

Loess.—The physical characters and probable æolian origin of this remarkable deposit having been already mentioned (p. 439), we may now consider it in reference to its place in geological history. In Central Europe it covers a wide area. Beginning on the French coast at Sangatte, it sweeps eastward across the north of France and Belgium (Hesbayan loam), filling up the lower depressions of the Ardennes, passing far up the valleys of the Rhine and its tributaries, the Necker, Main, and Lahr; likewise those of the Elbe above Meissen, the Weser, Mulde, and Saale, the Upper Oder and the Vistula. Spreading across Upper Silesia, it sweeps eastward over the plains of Poland and Southern Russia, where it forms the substratum of the Tschernozŏm or black-earth. It extends into Bohemia, Moravia, Hungary, Gallicia, Transylvania, and Roumania, sweeping far up into the Carpathians, where it reaches heights of 2000 and, it is said, even 4000 or 5000 feet above the sea. It has not been observed on the low Germanic plains south of the Baltic, nor south of Central France and the Alpine chain. Though thickest in the valleys (100 feet or more), it is not confined to them, but spreads over the plateaux and rises far up the flanks of the uplands. Near its edge, where it abuts against higher ground, it contains layers or patches of angular débris, but elsewhere it preserves a remarkable uniformity of texture.

In the United States the loess presents some differences from its European development. It is widely distributed in the great basin of the Mississippi, where it more especially keeps to the valleys, being thickest, coarsest, and most typical in the bluffs bordering the rivers and shading away from these places into finer material, a feature which suggests that in some way the deposit was connected with the operations of the great streams. On the other hand, it has a vertical range of not far short of 1000 feet, even within 20 miles may rise to 500 or 700 feet, and crosses the water-sheds, features for the explanation of which we can hardly suppose the great rivers to have been so flooded as to unite their waters over the dividing ridge and form a flood many hundred feet deep. There appears to be a close relation between the distribution of the loess and the edge of the former ice-sheet, suggesting that the deposit was connected with the ice. Again, it has been ascertained that there have been more than one interval during which loess has been formed, for it has been found in Wisconsin and elsewhere, sometimes with a thick soil on its upper surface, buried under till. It would thus appear that the causes which produced this singular deposit can be traced back into the Glacial period.[1]

The European loess is sometimes found resting on gravels containing remains of the mammoth. It may be observed to shade off into more

[1] In North America, as in Europe the loess has given rise to much discussion. See the papers cited on pp. 440, 1361.

recent alluvial accumulations. On this continent also, it is probably not all of one age, but has been deposited at many different heights during a prolonged period, beginning during a dry, cold interval of the Ice Age, and continuing until long after man had come upon the scene. Though on the whole not rich in fossils, the loess has yielded a peculiar fauna, which singularly confirms Richthofen's view that the deposit was a subaerial one. In the first place, the shells found in it are almost without exception of terrestrial species. Out of 211,968 specimens from the loess of the Rhine, Braun found only one brackish and three fresh-water forms, *Limnæa* and *Planorbis*, of which there were only 32 specimens in all. Of the rest, there were 98,502 examples of two species of *Succinea*, an amphibious genus, and 113,434 specimens belonging to 25 species of *Helix*, *Pupa*, *Clausilia*, *Bulimus*, *Limax*, and *Vitrina*—unquestionable terrestrial forms.[1] It is worthy of note that Helices and Succineas abound at present in the steppe-regions of Central Asia, and that many of the species of loess mollusks are now living in East Russia, south-west Siberia, and on the prairies of the Little Missouri in North America.[2] The abundant mollusks in the loess of Iowa and Nebraska are all land and fresh-water shells belonging to species still living in the region.[3]

From various parts of the European loess, Dr. Nehring has described a remarkable assemblage of animals, which included a jerboa (*Alactaga jaculus*), marmots (*Spermophilus*, several species), *Arctomys bobac*, tailless hare (*Lagomys pusillus*), numerous species of *Arvicola*, *Cricetus frumentarius*, *C. phæus*, porcupine (*Hystrix hirsutirostris*), wild horses, and antelopes (*Antilope saiga*). This fauna, excepting some extinct or extirpated species, is identical with that which now lives in the south-east European and south-west Siberian steppes.[4] Besides these distinctively steppe animals the loess contains numerous remains of the mammoth and woolly rhinoceros, likewise bones of the musk-sheep, hare, wolf, stoat, &c. It has also yielded flint implements of Palæolithic types. The bones of man himself were claimed many years ago by Ami Boué to have been found in the loess, and his opinion has been in some measure strengthened by more recent observations.

As already stated (p. 440), the problem of the loess has given rise to much discussion. It has been regarded by some writers as the deposit of a vast series of lakes; by others as the mud left by swollen rivers discharged from melting ice-fields;[5] by others as a sediment washed over

[1] *Zeitsch. für die gesammt. Naturwiss.* xl. p. 45, as quoted by H. H. Howorth, *Geol. Mag.* 1882, p. 14.

[2] A. Nehring, *Geol. Mag.* 1883, p. 57; *Neues Jahrb.* 1889, p. 66; 'Ueber Tundren und Steppen,' Berlin, 1890.

[3] B. Shimek, *Rep. Iowa Acad. Sci.* 1897.

[4] Nehring, *Geol. Mag.* 1883, p. 51, where a reference to this author's numerous memoirs on the subject will be found. See also J. N. Woldrich on the Steppe fauna, *Neues Jahrb.* 1897, ii. p. 159, and Nehring in same vol. p. 220.

[5] This view has been well expressed by Messrs. Chamberlin and Salisbury (*6th Ann. Rep. U.S. G. S.* 1885, and papers in *Journ. Geol.* since 1892), and by Mr. M'Gee (*11th Ann. Rep. U.S. G. S.* 1891). See also the writings of Prof. Calvin and his associates in the *Rep. Geol. Surv. Iowa*, and of Prof. Winchell and Mr. Upham in the *Rep. Geol Surv. Minnesota*.

the surface of the land by an abundant rainfall. The remarkably unstratified character of the loess as a whole, its uniformity in fineness of grain, the general absence of coarse fragments, except along its margin, where they might be expected, its singular independence of the underlying contour of the ground, and the almost total absence in it of fluviatile or lacustrine shells, seem to indicate that it cannot, as a whole, have been laid down by rivers or lakes, though it may, to a greater or less extent, have been derived from the desiccation and æolian transport of the fine sediment spread out on the flood-plains of glacial rivers. Its internal composition, the thoroughly oxidised condition of its ferruginous constituents, its distribution, and the striking character of its enclosed organic remains, point to its having been chiefly accumulated in the open air, probably in circumstances similar to those which now prevail in the dry steppe regions of the globe. It appears to mark one or more arid intervals after the height of the Glacial Period had passed away, when, whilst the climate still remained cold and the Arctic fauna had not entirely retreated to the north, a series of grassy and dusty steppes swept across the heart of Europe, Asia, and North America.[1]

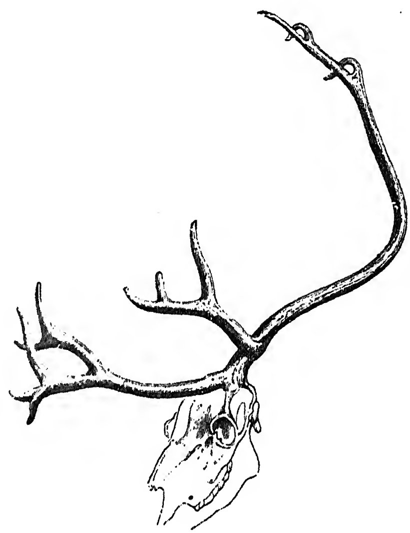

Fig. 496. Antler of Reindeer (Rangifer tarandus, Linn. (1/4) found at Bilney Moor, East Dereham, Norfolk.

Palæolithic Fauna. The mammalian remains found in Palæolithic deposits are remarkable for a mixture of forms from warmer and colder latitudes similar to that already noted among the interglacial beds. It has been inferred, indeed, that the Palæolithic gravels are themselves referable to interglacial conditions. On the one hand, we meet with a number of species of warmer habitat, as the lion, hyæna, hippopotamus, lynx, leopard, and caffer cat; and, in the loess, the

[1] The views propounded by Richthofen for the loess of China and applied by Nehring to that of Europe have been widely adopted by geologists (see, for example, C. Reid, *Geol. Mag.* 1884, p. 165; *Q. J. G. S.* xliii. 1887, p. 364; xlviii. 1892, p. 344; *Natural Science*, iii. 1893, p. 367. A. Smith Woodward, *Proc. Zool. Soc.* 1890, p. 613. T. F. Jamieson, *Geol. Mag.* 1890, p. 70). But, as stated above, they have not been universally received, one geologist contending that water in different ways has been concerned in the formation of the loess. See J. Geikie, 'Prehistoric Europe,' p. 241; *Rep. Brit. Assoc.* 1889, Address to Geol. Sect. Wahnschaffe, *Zeitsch. Deutsch. Geol. Ges.* xxxviii. (1886), p. 533. F. Sacco, *Bull. Soc. Géol. France*, xv. 1887, p. 229; the papers of Chamberlin, Salisbury, and M'Gee above cited, and others by W. Upham (*Amer. Geol.* xxxi. p. 25) and other writers in the United States.

assemblage of forms above referred to as that which still characterises the warm dry steppes of south-eastern Europe and southern Siberia.

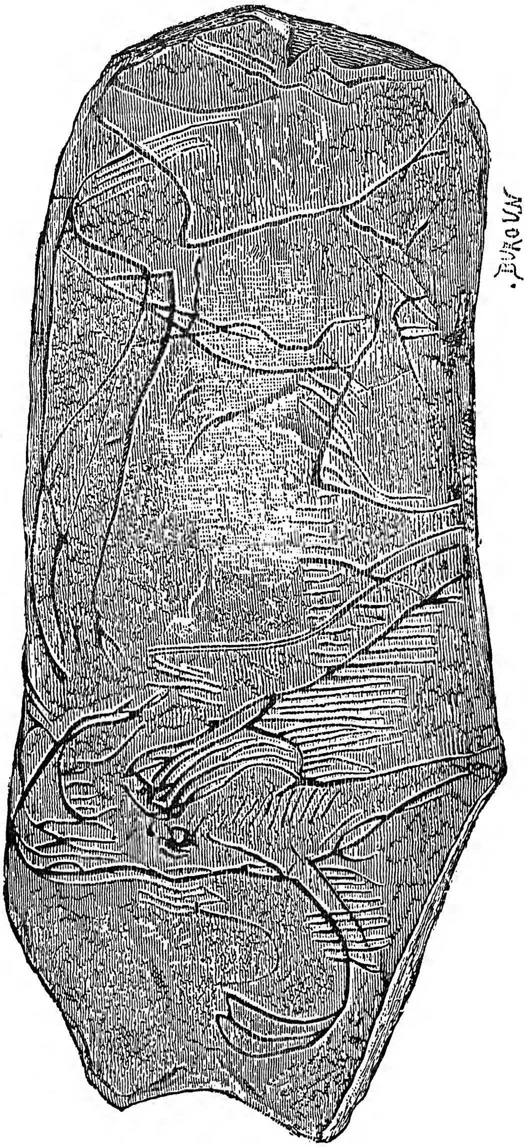

Fig. 497.—Figure of the Mammoth (Elephas primigenius, Blum.). Engraved on ivory by Cave-men La Madelaine, France (Lartet, 'Reliquiæ Aquitan').

But, on the other hand, a large number of the forms are northern, such as the glutton (*Gulo luscus*), Arctic fox (*Canis lagopus*), reindeer (*Rangifer tarandus*), Alpine hare (*Lepus variabilis*), Norwegian lemming (*Myodes

torquatus), Arctic lemming (*M. lemmus*, *M. obensis*), marmot (*Arctomys marmotta*), Russian vole (*Microtus ratticeps*), musk-sheep (*Ovibos moschatus*), snowy-owl (*Stryx nyctea*). There is likewise a proportion of now wholly extinct animals, which include the Irish elk (*Cervus giganteus* or *Megaceros hibernicus*), *Elephas primigenius* (mammoth), *E. antiquus*, *Rhinoceros megarhinus*, *R. antiquitatis* (*tichorhinus*) (woolly rhinoceros), *R. leptorhinus*, and cave-bear (*Ursus spelæus*).

The Palæolithic fauna has been divided into three sections, each supposed to correspond with a distinct period of time: 1st, the Age of *Elephas antiquus*, with which species are associated *Rhinoceros megarhinus* (*Merckii*) and *Hippopotamus amphibius* (*major*). 2nd, The Age of the mammoth, with the woolly rhinoceros, cave-bear, and cave-hyæna. 3rd, The Age of the reindeer, when that animal passed in great numbers across Central Europe. But, as already stated, such subdivisions are admittedly artificial, and should only be used as provisional aids in the comparison of deposits which cannot be tested by the law of superposition.

That man was contemporary with these various extinct animals is proved by the frequent occurrence of undoubtedly human implements, formed of roughly chipped flints, &c., associated with their bones. Much more rarely, portions of human skeletons have been recovered from the same deposits. The men of the time appear to have camped in rock shelters and caves, and to have lived by fishing and by hunting the reindeer, bison, horse, mammoth, rhinoceros, cave-bear, and other animals. That they were not without some kind of culture is shown by the vigorous incised sketches and carvings which they have left behind on reindeer antlers, mammoth tusks (Fig. 497), and other bones depicting the animals with which they were daily familiar. Some of these drawings are especially valuable, as they represent forms of life long ago extinct, such as the mammoth and cave-bear. Again, from the walls of a cave at Font-de-Gaume, near Eyzies in Dordogne, MM. Capitan and Breuil have brought to notice no fewer than eighty frescoes with incised outlines, and painted in tints of red and brown. Forty-nine of these represent bisons, which are drawn with great vigour. Among the paintings are those of two reindeer.[1] The men who in Palæolithic time inhabited the caves of Europe must have had much similarity, if not actual kinship, to the modern Eskimos.

NEOLITHIC.—The deposits whence the history of Neolithic man is compiled must vary widely in age. Some of them were no doubt contemporaneous with parts of the Palæolithic series, others with the Bronze and Iron series.[2] They consist of cavern deposits, alluvial accumulations, peat-mosses, lake-bottoms, pile-dwellings, and shell-mounds.

[1] *Compt. rend.* cxxxiv. (1902), p. 1536, where four of the frescoes are reproduced.

[2] It has generally been assumed that there is a hiatus between the records of the Palæolithic and those of the Neolithic ages, though some writers (as Mr. J. Allen Brown, *Journ. Anthrop. Instit.* 1892) have contended for their continuity. There is certainly no convincing evidence of any serious interruption. M. Piette has found at Mas d'Azil (Ariège) what he regards as evidence that bridges over this supposed gap. At that locality a bed of cinders containing Magdalenian types of implement is overlain by a layer full of raddled

The list of mammals, &c., inhabiting Europe during Neolithic is distinguished from that of Palæolithic time by the absence of the mammoth, woolly rhinoceros, and other extinct types, which appear to have meanwhile died out in Europe. The only form now extinct which appears to have survived into Neolithic time was the Irish elk, which may have continued to live until a comparatively late date.[1] The general assemblage of animals was probably much what it has been during the period of history, but with a few forms which have disappeared from most of Europe either within or shortly before the historic period, such as the reindeer, elk, urus, grizzly bear, brown bear, wolf, wild boar, and beaver. But besides these wild animals there are remains of domesticated forms introduced by the race which supplanted

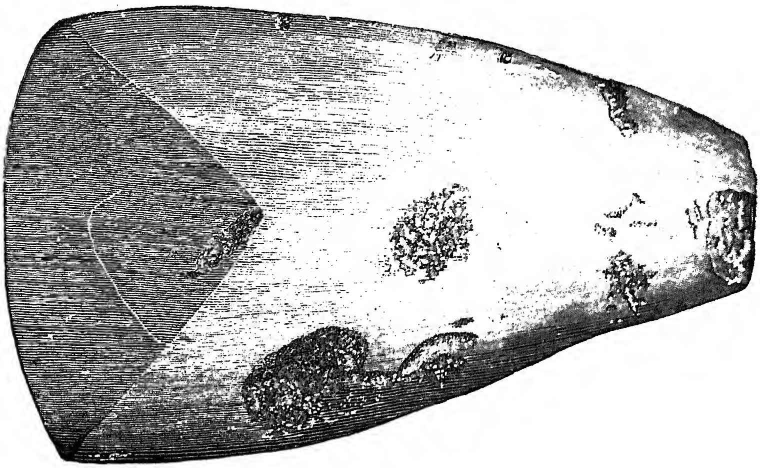

Fig. 498.—Neolithic Stone Implement.

the Palæolithic tribes. These are the dog, horse, sheep, goat, shorthorn, and hog. It is noteworthy that these domestic forms were not parts of the indigenous fauna of Europe. They appear at once in the Neolithic deposits, leading to the inference that they were introduced by the human tribes which now migrated, probably from Central Asia, into the European continent. These tribes were likewise acquainted with agriculture, for several kinds of grain, as well as seeds of fruits, have been found in their lake-dwellings; and the deduction has been drawn from these remains that the plants must have been brought from

pebbles (like those of some kitchen middens) without any trace of the reindeer, which is supposed to have become extinct in the region, but with remains of red deer, wild boar, ox, and beaver, jaws and vertebræ of fishes, and numerous harpoons with which the early men fished in the neighbouring river Arise. A considerable number of traces of fruits and seeds have likewise been obtained, including the oak, hawthorn, black thorn, filbert, chestnut, cherry, plum, walnut, and wheat. *Bull. Soc. Anthrop.* 1895, *L'Anthropologie*, vii.

[1] *Geol. Mag.* 1881, p. 354; *Nature*, xxvi. p. 246.

Southern Europe or Asia. The arts of spinning, weaving, and pottery-making were also known to these people. Human skeletons and bones belonging to this age have been met with abundantly in barrows and peat-mosses, and indicate that Neolithic man was of small stature, with a long or oval skull.

The history of the Bronze and Iron Ages in Europe is told in great fulness, but belongs more fittingly to the domain of the archæologist, who claims as his proper field of research the history of man upon the globe. The remains from which the record of these ages is compiled are objects of human manufacture, graves, cairns, sculptured stones, &c., and their relative dates have in most cases to be decided, not upon

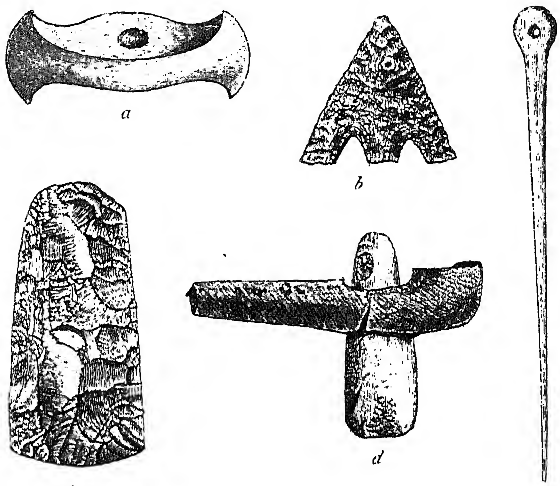

Fig. 499.—Neolithic Implements.

a, Stone axe-head ($\frac{1}{3}$); *b*, Barbed flint arrow-head (natural size); *c*, Roughly-chipped flint celt ($\frac{1}{3}$); *d*, Polished celt ($\frac{1}{2}$), with part of its original wooden hand still attached, found in a peat-bog, Cumberland; *e*, Bone-needle (natural size), Swiss Lake Dwellings; *a*, *b*, *c*, *d*, reduced from Sir J. Evans's "Ancient Stone Implements."

geological, but upon archæological grounds. When the sequence of human relics can be shown by the order in which they have been successively entombed, the inquiry is strictly geological, and the reasoning is as logical and trustworthy as in the case of any other kind of fossils. Where, on the other hand, as so often happens, the question of antiquity has to be decided solely by relative finish and artistic character of workmanship, it must be left to the experienced antiquary.

§ 2. Local Development.

A few examples of the nature of the deposits of the Palæolithic and Neolithic series in different parts of the world will suffice to show the general character of the evidence which they supply.

Britain.—Palæolithic deposits are absent from the north of England and from Scotland. They occur in the south of England, and notably in the valley of the Thames. In that district, a series of brick-earths with intercalated bands of river-gravel, having a united thickness of more than 25 feet, is overlain with a remarkable bed of clay, loam, and gravel ("trail"), three feet or more in thickness, which in its contorted bedding and large angular blocks probably bears witness to its having been accumulated during a time of floating ice. The strata below this presumably glacial deposit have yielded a remarkable number of mammalian bones, among which have been found undoubted human implements of chipped flint. The species include *Rhinoceros leptorhinus*, *R. antiquitatis* (*tichorhinus*), *R. megarhinus*, *Elephas antiquus*, *E. primigenius*, *Cervus giganteus* (*Megaceros hibernicus*), *C. elaphus*, *Capreolus caprea*, *Rangifer tarandus*, *Bos taurus* var. *longifrons*, *Bos primigenius*, *Bison priscus*, *Felis leo*, *Hyæna crocuta*, *Canis lupus*, *Ursus spelæus*, *U. arctos*, *Ovibos moschatus*, *Hippopotamus amphibius* (*major*), and present another example of the mingling of northern with southern, and of extinct with still living forms, as well as of species which have long disappeared from Britain with others still indigenous. Other ancient alluvia, far above the present levels of the rivers, have likewise furnished similar evidence that man continued to be the contemporary in England of the northern rhinoceros and mammoth, the reindeer, grizzly bear, brown bear, Irish elk, hippopotamus, lion, and hyæna.

As an illustration of the relation of the implement-bearing brick earth loams and gravels to the glacial deposits, and those containing remains of an Arctic flora the following section, obtained by Mr. C. Reid at Hoxne, Suffolk, where for more than a century numerous palæolithic implements have been dug up, affords interesting evidence as to the oscillations of climate at the close of the Glacial, or beginning of the Recent Period.[1]

Bluish-green loam or brick-earth and laminated loams (11 feet). This deposit has furnished the flint implements, together with bones of *Equus*, *Cervus*, *Bos*, *Elephas*, and numerous species of fresh-water shells which are still living in the neighbourhood. The climate indicated may have been much like that of the present time.

Fine gravel (2 or 3 feet), yielding worked flints and implements.

Black earth (13 feet), consisting of carbonaceous loam, sand, and vegetable matter, with no implements or remains of the large mammals, but with fish bones, scattered fresh-water shells, and abundant leaves belonging to three species of dwarf Arctic willow, more rarely to the dwarf Arctic birch, indicating on the whole an Arctic or high Alpine flora.

Lignite (1 to 3 feet), made up of plants of temperate character, including 37 species of flowering plants still living in the district.

Lacustrine clay (about 20 feet), containing remains of fresh-water fishes and shells, with leaves and various fragments of marsh-loving and other plants of temperate type.

The caverns in the Devonian, Carboniferous, and Magnesian limestones of England have yielded abundant relics of the same prehistoric fauna, with associated traces of Palæolithic man. In some of these places, the lowest deposit on the floor contain rude flint implements of the same type as those found in the oldest river-gravels, while others of a more finished kind occur in overlying deposits, whence the inference has been drawn that the caverns were first tenanted by a savage race of extreme rudeness, and afterwards by men who had made some advance in the arts of life. The association of bones shows that when man had for a time retired, some of these caves became hyæna dens. Hyæna bones in great numbers have been found in them (remains of no fewer than 300 individuals were taken out of the Kirkdale cave), together with abundant gnawed bones of the animals on which the hyænas preyed, and quantities of hyæna excrement. Holes in the limestone opening to the surface (sinks, swallow-holes) have likewise become receptacles for the remains of many generations of animals which fell

[1] *Brit. Assoc.* 1896, p. 400. See also *Proc. Roy. Soc.* lxi. (1897), p. 40.

into them by accident, or crawled into them to die. In a fissure of the limestone near Castleton, Derbyshire, from a space measuring only 25 by 18 feet, no fewer than 6800 bones, teeth, or fragments of bone were obtained, chiefly bison and reindeer, with bears, wolves, foxes and hares.[1] The length of time during which some of the fissures in a limestone district may remain open as a trap for the entombment of the land animals of the country is well illustrated by the instance at Ightham, Kent, where among abundant remains of the living fauna of the neighbourhood there are found also those of a number which have long been absent from Britain, such as the wolf, bear, and hyæna, together with northern types like the Arctic fox and reindeer, and the long extinct mammoth.[2]

France.—It was in the valley of the Somme, near Abbeville, that Boucher de Perthes made the first observations which led the way to the recognition of the high antiquity of man upon the earth. That valley has been eroded out of the Chalk, which rises to a height of from 200 to 300 feet above the modern river. Along its sides, far above the present alluvial plain, are ancient terraces of gravel and loam, formed at a time when the river flowed at higher levels. The lower terrace of gravel, with a covering of flood-loam, ranges from 20 to 40 feet in thickness, while the higher bed is about 30 feet. Since their formation, the Somme has eroded its channel down to its present bottom, and may have also diminished in volume, while the terraces have, during the interval, here and there suffered from denudation. Flint implements have been obtained from both terraces, and in great numbers, associated with bones of mammoth, rhinoceros, and other extinct mammals (p. 1336). More recently a remarkable association of worked flints, with the remains of *Elephas meridionalis*, *E. antiquus*, and *E. primigenius*, have been found in a ballast-pit in gravelly drift at Tilloux, near Gensac-la-Pallue, Charente.[3]

The caverns of the Dordogne and other regions of the south of France have yielded abundant and varied evidence of the coexistence of man with the reindeer and other animals either wholly extinct or no longer indigenous. So numerous in particular are the reindeer remains, and so intimate the association of traces of man with them, that the term "Reindeer period" has been proposed for the section of prehistoric time to which these interesting relics belong. The art displayed in the implements found in the caverns appears to indicate a considerable advance on that of the chipped flints of the Somme. Some of the pictures of reindeer and mammoths, incised on bones of these animals, and the frescoes already mentioned, are singularly spirited (Fig. 497).

Germany. From various caverns, particularly in the dolomite of Franconia (Muggendorf, Gailenreuth) and in the Devonian limestone of Westphalia and Rhineland, remains of extinct mammals have been obtained, sometimes in great numbers, including cave-bear (of which the remains of 800 individuals have been taken out of the Gailenreuth cave), hyæna, lion, rhinoceros, and others. From the cavern of Hohlefels in Swabia remains of elephants, rhinoceroses, reindeer, antelopes, horses, cave-bears, and other animals have been found, together with interesting proofs of the contemporaneity of man, in the form of rude flint implements, axes of bone, or teeth and bones which he had bored through, or split open for their marrow. At Schussenried in the Swabian Saulgau, not far from the Lake of Constance, beneath a deposit of calcareous tufa enclosing land-shells, there is a peaty bed containing Arctic and Alpine mosses, together

[1] Boyd Dawkins, 'Early Man in Britain," p. 188. The reindeer has not been found in such abundance in the English caverns as in those of Southern France; but its bones have been met with in some number in the old alluvium of the Thames valley. *Q. J. G. S.* l. (1890), p. 461.

[2] W. J. Lewis Abbott and E. T. Newton, *Q. J. G. S.* l. (1894), pp. 171-210 and lv. (1899), p. 419.

[3] M. Boule, *L'Anthropologie*, vi. (1895), p. 497. A voluminous memoir by M. Rutot, on the age of deposits with worked flints, in the province of Hainaut, Belgium, will be found in *Bul. Soc. Anthropologie*, Brussels, xvii. (1899).

with abundant remains of reindeer, also bones of the glutton, Arctic fox, brown fox, polar bear, horse, &c. While this truly Arctic assemblage of animals lived near the foot of the Alps, man also was their contemporary, as is shown by the presence, in the same deposit, of his flint implements, stones that have been blackened by fire, bones of the reindeer and horse that have been broken open for their marrow, needles of wood and bone, and balls of red pigment probably used for painting his body.[1]

Switzerland.—The lakes of Switzerland, as well as those of most other countries in Europe, have yielded in considerable numbers the relics of Neolithic man. Dwellings constructed of piles ("crannoges" of Ireland) were built in the water out of arrow-shot from the shore. Partly from destruction by fire, partly from successive reconstructions, the bottom of the water at these places is strewn with a thick accumulation of débris, from which vast numbers of relics of the old population have been recovered, revealing much of their mode of life.[2] Some of these settlements probably date far back beyond the beginning of the historic period. Others belong to the Bronze, and to the Iron Age. The same site would no doubt be used for many generations, so that successive layers of relics of progressively later age would be deposited on the lake-bottom. It is believed that in some cases the lacustrine dwellings were still used in the first century of our era.

Denmark.—The shell-mounds (*Kjökken-möddinger*), from 3 to 10 feet high, and sometimes 1000 feet long, heaped up on various parts of the Danish coast-line, mark settlements of the Neolithic age. They are made up of refuse, chiefly shells of mussels, cockles, oysters, and periwinkles, mingled with bones of the herring, cod, eel, flounder, great auk, wild duck, goose, wild swan, capercailzie, stag, roe, wild boar, urus, lynx, wolf, wild cat, bear, seal, porpoise, dog, &c., with human tools of stone, bone, horn, or wood, fragments of rude pottery, charcoal, and cinders.[3]

The Danish peat-mosses have likewise furnished relics of the early human races in that region. They are from 20 to 30 feet thick, the lower portion containing remains of Scotch fir (*Pinus sylvestris*) and Neolithic implements. This tree has never been indigenous in the country within the historic period.[4] A higher layer of the peat contains remains of the common oak with bronze implements, while at the top come the beech-tree and weapons of iron.[5]

Finland.—In Finland a study of the peat-mosses, which cover about a fifth part of the surface of the country, has furnished a corresponding record of the changes of

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[1] O. Fraas, *Archiv für Anthropologie*, Brunswick, 1867.

[2] Keller's 'Lake Dwellings of Switzerland.'

[3] J. J. Steenstrup, 'Kjökken Möddinger,' Copenhagen, 1886. Similar mounds of fish-offal and whelk and other shells, mingled with broken pottery and other refuse, may be seen in course of accumulation at many fishing villages on the east coast of Scotland, where also prehistoric kitchen-middens have been found.

[4] An interesting discussion of the subject of the migration of the spruce-fir into Scandinavia by G. Andersson and R. Sernander will be found in the 14th vol. of *Geol. Fören. Stockholm* (1892), and in Engler's *Botan. Jahrb.* xv. (1892). The history of the Scandinavian flora, and its bearing on changes of climate, have engaged much attention among the geologists of Sweden, Norway, and Finland, *e.g.* Nathorst, *Geol. Fören. Stockholm*, vii. G. Andersson, xiv. pp. 509-538 (an important resumé of the subject); "Studier öfver Finlands Torfmossar." *Bull. Com. Géol. Finlande*, No. 8, 1898 (a detailed account of plants found in the Finnish peat-bogs, and a partial discussion of the geological history indicated by them). H. Hedström, *Geol. Fören. Stockholm*, xv. (1893), p. 291 (on the former and present distribution of the hazel). R. Sernander, p. 345 (on the climate and vegetation of the *Littorina*-period). J. Helmboe, xxii. (1900), p. 55 (a detailed account of sections of two peat-bogs in the Christiania district, with an enumeration of the plants in the several layers). G. Lagerheim, xxiii. (1901), p. 469 (a discussion of the rhizopods, &c., in Swedish and Finnish lacustrine deposits, including peat). J. J. Sederholm, *Bull. Com. Géol. Finlande*, No. 10, p. 23.

[5] See Steenstrup's "Kjökken Möddinger"; Nathorst, *Nature*, 1889, p. 453.

climate as registered by the remains of the vegetation. At the bottom of the peat the Arctic willow, dwarf birch, and other plants betoken the continuance of a severe climate. Higher up come the relics of pine-trees. These in the southern districts were followed during the *Littorina*-period by the oak, joined soon after by the spruce. That period, if we may judge from the evidence of the peat-mosses, was rather warmer than the present, inasmuch as plants are found in these deposits which now live in more genial countries. In Norway a record of some of these changes in the flora has been preserved in deposits of calc-sinter.[1]

North America.—Prehistoric deposits are essentially the same on both sides of the Atlantic. In North America, as in Europe, no very definite lines can be drawn within which they should be confined. They cannot be sharply separated from the Champlain series on the one hand, nor from modern accumulations on the other. Besides the marshes, peat-bogs, and other organic deposits which belong to an early period in the human occupation of America, some of the younger alluvia of the river-valleys and lakes can no doubt claim a high antiquity, though they have not supplied the same copious evidence of early man which gives so much interest to the corresponding European formations. From the peat-bogs of the eastern States, and from the older alluvium of the Missouri River, the remains of the gigantic mastodon have been obtained. There have likewise been found bones of reindeer, elk, bison, beaver, horse (six species), lion, and bear; while southwards those of extinct sloths (*Mylodon*, *Megatherium*) make their appearance. In California, from the deep auriferous gravels remains of mastodon and other extinct animals have been met with, also human bones, stone spear-heads, mortars, and other implements. Professor Whitney described the famous Calaveras skull as occurring at a depth of 120 feet in undisturbed gravel which is covered with a sheet of basalt. If genuine, the specimen, with the human works of art said to occur in the same deposits, would indicate the existence of man, perhaps as advanced in some respects as the modern Indian tribes of the same region, in Pliocene or Miocene time. The validity of these remains, however, has been strongly contested, and on the whole the balance of evidence seems to be against them. Human skeletons and stone implements have been exhumed from the loess and other quaternary deposits in a number of places in the United States, and the inference has been drawn from them by some observers that man existed in North America during the later stages of the Ice Age. Other writers, however, have disputed this conclusion, contending that the supposed inclusion of the remains in the loess is deceptive, that they really belong to a much later time, and that in other cases the implements, thought to have been evidence of early man, were the work of modern Indians.[2]

[1] Axel Blytt, *Englers. Botan. Jahrb.* xvi. (1892), ii. Beiblatt, No. 36.

[2] J. D. Whitney, *Mem. Mus. Compar. Zool. Harvard*, vi. (1880). The evidence adduced in support of the great antiquity of man in America, and his contemporaneity with the Mastodon and other extinct animals, is summarised by the Marquis de Nadaillac in his 'L'Amérique Préhistorique' (translated by N. d'Anvers, 1885). The controversy over the Calaveras skull is summed up by W. H. Holmes, *Smithsonian Report* for 1899, pp. 419-472, with 16 plates. More recent and perhaps less doubtful proof of palæolithic man has been cited from the gravels of the Delaware River at Trenton, of the Miami River in Southern Ohio, and of the Mississippi at Little Falls, Minnesota. On the side of the antiquity of man, see H. C. Lewis, *Proc. Min. Geol. Sect. Acad. Philadelphia*, 1879; F. W. Putnam, C. C. Abbott, G. F. Wright, W. Upham, &c., on Palæolithic man in eastern and central North America, *Proc. Boston Soc. Nat. Hist.* xxiii. (1888), p. 421; G. F. Wright, 'Ice Age in North America,' and 'Man in the Glacial Period' (1892), also *Popular Science Monthly*, May 1893, and recent papers by W. Upham, *Amer. Geol.* 1902, 1903. On the other side, consult especially the papers of W. H. Holmes and T. C. Chamberlin. The latest example of disputed evidence is that of the human skeleton said to have been exhumed from undisturbed loess at Lansing, Kansas. This example, fully described by Mr. Upham

Heaps of shells of edible species, like those of Denmark, occur on the coasts of Nova Scotia, Maine, &c. The large mounds of artificial origin in the Mississippi valley have excited much attention. The early archæology of these regions is full of interest.

In South America, the loams of the Pampas have furnished abundant remains of horses, tapirs, lamas, mastodons, wolves, panthers, with gigantic extinct sloths and armadillos (*Megatherium*, *Glyptodon*).[1]

Australasia.—No line can be drawn in this region between accumulations of the present time and those which have been called Pleistocene. The modern alluvia have been formed under similar conditions to those under which the older alluvia were laid down, though possibly with some differences of climate. In New South Wales, ossiferous caverns contain bones of some of the extinct marsupial animals mentioned on p. 1299 mingled with those of some of the species which are still living in the same places. In one locality in the same colony, in sinking a well, teeth of crocodiles were found with bones of *Diprotodon*, &c. No human remains have yet been found associated with those of the extinct animals; but a stone hatchet was taken out of alluvium at a depth of 14 feet.[2]

In New Zealand, the most interesting feature in the younger geological accumulations is the presence of the bones of the large bird *Dinornis*, which has become extinct since the Maoris peopled the islands. The evidences of the human occupation of the country are confined to the surface-soil, shelter-caves, and sand-dunes.[3]

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and Prof. Winchell, is regarded by them as proof of the contemporaneity of man with the later phases of the Ice Age in the Missouri Valley (*Amer. Geol.* xxx. 1902, pp. 135, 189; xxxi. 1903, p. 25). On the other hand, a careful scrutiny of the locality by Professors Holmes, Chamberlin, Calvin, and Salisbury has led them to consider the overlying deposit as not loess, but a much younger and post-glacial alluvium (*Journ. Geol.* x., 1902, p. 745). It would appear, moreover, that the age of such deposits cannot be determined from the character of the human handiwork found in them, since Mr. Holmes has shown that implements of Palæozoic type continued to be made by the aboriginal inhabitants of Indian Territory, and the very quarry from which they obtained their material has been found, together with specimens of their various implements, in different stages of preparation. "An Ancient Quarry in Indian Territory," by W. H. Holmes, *Rep. Bureau, Ethnology*, Washington, 1894.

[1] See Florentino Ameghino, 'La Antiquedad del Hombre en el Plata,' where a good account of the Pampas country will be found.

[2] C. S. Wilkinson, 'Notes on Geology of New South Wales,' 1882, p. 59.

[3] Hector, 'Handbook of New Zealand,' p. 25.

BOOK VII.

PHYSIOGRAPHICAL GEOLOGY.

An investigation of the geological history of a country involves two distinct lines of inquiry. We may first consider the nature and arrangement of the rocks that underlie the surface, with a view to ascertain from them the successive changes in physical geography and in plant and animal life which they chronicle. But besides the story of the rocks, we may try to trace that of the surface itself—the origin and vicissitudes of the mountains and plains, valleys and ravines, peaks, passes, and lake-basins which have been formed out of the rocks. The two inquiries traced backward merge into each other; but they become more and more distinct as they are pursued towards later times. It is obvious, for instance, that a mass of marine limestone which rises into groups of hills, trenched by river-gorges and traversed by valleys, presents two sharply contrasted pictures to the mind. Looked at from the side of its origin, the rock brings before us a sea-bottom over which the relics of generations of a luxuriant marine calcareous fauna accumulated. We may be able to trace every bed, to mark with precision its organic contents, and to establish the zoological succession of which these superimposed sea-bottoms are the records. But we may be quite unable to explain how such sea-formed limestone came to stand as it now does, here towering into hills and there sinking into valleys. The rocks and their contents form one subject of study; the history of their present scenery forms another.

The branch of geological inquiry which deals with the evolution of the existing contours of the dry land is termed Physiographical Geology. To be able to pursue it profitably, some acquaintance with all the other branches of the science is requisite. Hence its consideration has been reserved for this final division of the present work; but only a rapid summary can be attempted here.[1]

[1] A copious bibliography of this subject might now be prepared, in which the successive contributions of the various geological schools, from those of the early Italian writers down to those of Hutton and Playfair, would be enumerated. After the revival of interest in this branch of inquiry in the latter half of last century, the earlier writings mainly dealt

At the outset one or two fundamental facts may be stated. It is evident that the materials of the greater part of the dry land have been laid down upon the floor of the sea. That they now not only rise above the sea-level, but sweep upwards into the crests of lofty mountains, can only be explained by displacement. Thus the land owes its existence mainly to upheaval of the terrestrial crust, though it may have been to some extent increased and diminished by other causes (*ante*, p. 377 *et seq.*). The same sedimentary materials which demonstrate the fact of displacement, afford an indication of its nature and amount. Having been laid down in wide sheets on the sea-bottom, they must have been originally, on the whole, level or at least only gently inclined. Any serious departure from this original position must therefore be the effect of displacement, so that stratification forms a kind of datum-line from which such effects may be measured.

Further, it is not less apparent that sedimentary rocks, besides having suffered from disturbance of the crust, have undergone extensive denudation. Even in tracts where they remain horizontal, they have been carved into wide valleys. Their detached outliers stand out upon the plains as memorials of what has been removed. Where, on the other hand, they have been thrown into inclined positions, the truncation of their strata at the surface points to the same universal degradation. Here, again, the lines of stratification may be used, as on denuded anticlines, to measure approximately the amount of rock which has been worn away.

While, therefore, it is true that, taken as a whole, the dry land of the globe owes its existence to upheaval, it is not less true that its present contours are due largely to erosion. These two antagonistic forms of geological energy have been at work from the earliest times, and the existing land with all its varied scenery is the result of their combined operation. Each has had its own characteristic task. Upheaval has, as it were, raised the rough block of marble, but erosion has carved that block into the graceful statue.

The very rocks of which the land is built up bear witness to this

with principles as displayed in concrete examples, but are none the less important for their local origin, and they paved the way for more general treatises. The following list comprises only a few of the works that might be cited: A. C. Ramsay, 'The Physical Geology and Geography of Great Britain,' 1863; sixth edit. edited by H. B. Woodward 1894. A. G., 'The Scenery of Scotland viewed in connection with its Physical Geology,' 1865; fourth edit. 1901; a sketch of the physiography of the British Isles, *Nature*, xxix. (1884), pp. 325, 347, 396, 419, 442. E. Hull, 'The Physical Geology and Geography of Ireland,' 1878; second edit. 1891. J. Lubbock (Lord Avebury), 'The Scenery of Switzerland,' 1896; 'The Scenery of England,' 1902. G. de la Noë and E. de Margerie, 'Les Formes du Terrain,' Paris, 1888. A. Penck, 'Morphologie der Erdoberfläche,' 2 vols. Stuttgart, 1894. E. Suess, 'Antlitz der Erde' and its French translation, 'La Face de la Terre.' T. Mellard Reade, 'Origin of Mountain Ranges.' W. M. Davis, 'Physical Geography,' Boston, U.S.A. 1898. J. Geikie, 'Earth Sculpture.' J. E. Marr, 'The Scientific Study of Scenery,' 1900. Numerous papers discussing parts or the whole of the subject will be found in the scientific journals of the last thirty years, to some of which reference will be made in later pages.

intimate co-operation of hypogene and epigene agency. The younger stratified formations have been to a large extent derived from the waste of the older, the same mineral ingredients being used over and over again. This could not have happened but for repeated uplifts, whereby the sedimentary accumulations of the sea-floor were brought within reach of the denuding agents. Moreover, the internal characters of the great majority of these formations point unmistakably to deposition in comparatively shallow water. Their abundant intercalations of fine and coarse materials, their constant variety of mineral composition, their sun-cracks, ripple-marks, rain-pittings, and worm-tracks, their numerous unconformabilities and traces of terrestrial surfaces, together with the prevalent facies of their organic contents, combine to demonstrate that the main mass of the sedimentary rocks of the earth's crust was accumulated not far from land, and that no trace of really abysmal deposits, comparable to those of the deep ocean basins of the present day, has yet been found among them. From these considerations we are led up to the conclusion that the present continental areas must have been terrestrial regions of the earth's surface from a remote geological period. Subject to repeated oscillations, so that one tract after another has disappeared and reappeared from beneath the sea, the continents, though constantly varying in shape and size, have yet, I believe, maintained their individuality. We may infer, likewise, that the existing ocean-basins have probably always been the great depressions of the earth's surface.[1]

As already stated (p. 394), it is the general belief among geologists that mainly to the effects of the secular contraction of our planet are the deformations and dislocations of the terrestrial crust to be ascribed. The cool outer shell is supposed to have sunk down upon the more rapidly contracting hot nucleus, the enormous lateral compression thereby produced having the effect of throwing the crust into undulations, and even into the most complicated corrugations.[2] Hence, in the places where the

[1] See J. D. Dana, *Amer. Journ. Sci.* (2) ii. (1846) p. 352; "Geology" in 'Wilkes, Exploring Expedition,' 1849; *Amer. Journ. Sci.* (2) xxii. (1856); 'Manual of Geology,' 1863, and subsequent editions. Darwin, 'Origin of Species,' 1st edit. p. 343. L. Agassiz, *Bull. Mus. Comp. Zool.* 1869, vol. i. No. 13. J. D. Whitney, *Mem. Mus. Comp. Zool. Harvard*, vii. No. 2, p. 210. See also *Proc. Roy. Geograph. Soc.* new ser. i. (1879), p. 422. The contrary view that land and sea have continually changed places over the surface of the globe was held by Lyell, and is still maintained by some geologists. For a statement of geological evidence in favour of the interchange of terrestrial and marine areas the student may consult the memoirs of the late Professor Neumayr, cited on p. 1129. The opinion that land was once connected across what are now wide and deep seas has been based by naturalists on the difficulty of otherwise accounting for the affinities between the faunas of distant countries such as that of South America with Australia and that of Madagascar with Ceylon. It is quite credible, however, that in Arctic and possibly also in Antarctic regions there may have been more continuous land than at present (chains of islands and shallow seas), across which in periods of mild polar climate there might be a migration of plants and animals without having recourse to the supposition that the great ocean-basins were once crossed by masses of land.

[2] The Rev. O. Fisher, in his 'Physics of the Earth's Crust,' maintains that the secular contraction of a solid globe through mere cooling will not account for the observed phenomena. See *ante*, p. 66.

crust has yielded to the pressure, it must have been thickened, being folded or pushed over itself, or being perhaps thrown into double bulges, one portion of which rises into the air while the corresponding portion descends into the interior, as suggested by Mr. Fisher, who believes that such a downward bulging of the lighter materials of the crust into a heavier substratum underneath the great mountain-uplifts of the surface is indicated by the observed diminution in the normal rate of augmentation of earth-temperature beneath mountains,[1] and by the lessened deflection of the plumb-line in the same regions.

The close connection between upheaval and denudation on the one hand and depression and deposition on the other has often been remarked, and striking examples of it have been gathered from all parts of the world. It is a familiar fact that along the central and highest parts of a mountain chain, the oldest strata have been laid bare after the removal of an enormous thickness of later deposits. The same region still remains high ground, even after prolonged denudation. Again, in areas where thick accumulations of sedimentary material have taken place, there has always been contemporaneous subsidence which, as the strata have generally been deposits of shallow water, was necessary for their continued deposition. So close and constant is this relationship, as to have suggested the doctrine of "isostasy," that is, the belief that denudation by unloading the crust allows it to rise, while deposition by loading it causes it to sink (*ante*, p. 396).

It is evident that in the results of terrestrial contraction on the surface of the whole planet, subsidence must always have been in excess of upheaval—that in fact upheaval has only occurred locally over areas where portions of the crust have been ridged up by the enormous tangential thrust of adjacent subsiding regions. The tracts which have thus been, as it were, squeezed out under the strain of contraction have been weaker parts of the crust, and have usually been made use of again and again during geological time. They form the terrestrial regions of the earth's surface. Thus, the continents as we now find them are the result of many successive uplifts, corresponding probably to concomitant depressions of the ocean bed. In the long process of contraction, the earth has not contracted uniformly and equably. There have been, no doubt, vast periods during which no appreciable or only excessively gradual movements took place; but there have probably also been intervals when the accumulated strain on the crust found relief in more or less rapid collapse.

The general result of such terrestrial disturbances has been to throw the crust of the earth into wave-like undulations. In some cases, a wide area has been upheaved as a broad low arch, with little disturbance of the original level stratification of its component rocks. More usually, the undulations have been impressed as more sensible deformations of the crust, varying in magnitude from the gentlest appreciable roll up to mountainous crests of complicated plication, inversion, and fracture.

[1] The rate observed in the Mont Cenis and Mont St. Gothard tunnels was about 1° Fahr. for every 100 feet, or only about half the usual rate.

As a rule, the undulations have been linear, but their direction has varied from time to time, having been determined at right angles, or approximately so, to the trend of the lateral pressure that produced them. The upward folds of the crust have given birth to continents, while the downward folds have formed the ocean basins. These folds, however, are usually not simple arches and troughs, but include subsidiary folds within these. Thus the Atlantic trough is marked by a central ridge, the highest portions of which appear above sea-level in groups of islands, while the American arch has been plicated along its western border into the great chain of the Rocky Mountains and Andes, and near its eastern margin by less continuous and lofty ranges, and bears a vast geosyncline in the centre. As the crust has thickened, in consequence of the structure imparted to it by successive subsidences, certain portions of it have acquired more or less immobility, and have served as buttresses against which surrounding areas have been pressed and dislocated by subsequent movements. Suess has pointed out various areas of the earth's surface, named by him "Horsts," which seem to have served this purpose in the general rupture and subsidence of the terrestrial crust.

Considered with reference to their mode of production, the leading contours of a land-surface may be grouped as follows:—1. Those which are due more or less directly to disturbance of the crust. 2. Those which have been formed by volcanic action. 3. Those which are the result of denudation.

1. Terrestrial Features due more or less directly to Disturbance of the Crust.—In some regions, large areas of stratified rocks have been raised up with so little trace of curvature, that they seem to the eye to extend in horizontal sheets as wide plains or tablelands. If, however, these areas can be followed sufficiently far, the flat strata are eventually found to sweep upward into abrupt plications, as in the Rocky Mountains, or to curve down slowly or rapidly, or to be truncated by dislocations. In an elevated region of this kind, the general level of the ground corresponds, on the whole, with the planes of stratification of the rocks. Vast regions of Western America, where Cretaceous and later strata extend in nearly horizontal sheets for thousands of square miles at heights of 4000 feet or more above the sea, may be taken as illustrations of this structure. So abrupt is the upturn of the younger rocks of the eastern plains against the older masses of the Rocky Mountains that it is hardly an exaggeration to say that one may sit on the horizontal and lean his back against the vertical beds.

As a rule, curvature is more or less distinctly traceable in every region of uplifted rocks. Various types of flexure may be noticed, of which the following are some of the more important:—

(*a*) *Monoclinal Flexures* (p. 674).—These occur most markedly in broad plateau-regions and on the flanks of large broad uplifts, as in the tablelands of Utah, Wyoming, &c. They are frequently replaced by faults, of which indeed they may be regarded as an incipient stage (p. 691).

(*b*) *Symmetrical Flexures*, where the strata are inclined on the two

sides of the axis at the same or nearly the same angle. They may be low gentle undulations, or may increase in steepness till they become short sharp curves. Admirable illustrations of different degrees of inclination may be seen in the ranges of the Jura[1] (Fig. 500) and the Appalachians (Fig. 253), where the influence of this structure of the rocks on external scenery may be instructively studied. In many instances, each anticline forms a long ridge, and each syncline runs as a corresponding and parallel valley. It will usually be observed, however, that the surface of the ground does not strictly conform, for more than a short distance, to the surface of any one bed; but that, on the contrary, it passes across the edges of successive beds, as in Fig. 500. This relation —so striking a proof of the extent to which the surface of the land has suffered from denudation—may be followed through successive phases until the original superficial contours are exactly reversed, the ridges running along the lines of syncline and the valleys along the lines of anticline (Figs. 251, 252). Among the older rocks of the earth's crust which have been exposed alike to curvature and prolonged denudation, this reversal may be considered to be the rule rather than the exception.

Fig. 500.—Symmetrical Flexures of Swiss Jura (the ridges coinciding with anticlines and the valleys with synclines).

The tension of curvature may occasionally have produced an actual rupture of the crest of an anticline along which the denuding agents would effectively work.

The *Uinta type* is a variety of this structure seen to great perfection in the Uinta Mountains of Wyoming and Utah. It consists of a broad flattened flexure from which the strata descend steeply or vertically into the low grounds, where they quickly resume their horizontality. In the Uinta Mountains, the flat arch has a length of upwards of 150 and a breadth of about 50 miles, and exposes a vast deeply trenched plateau with an average height of 10,000 to 11,000 feet above the sea, and 5000 to 6000 feet above the plains on either side. This elevated region consists of nearly level ancient Palæozoic rocks, which plunge below the Secondary and Tertiary deposits that have been tilted by the uplift (Fig. 501). Powell believed that a depth of not less than three and a half miles of strata has been removed by denudation from the top of the arch.[2] In some places, the line of maximum flexure at the side of

[1] On the Jura see C. Clerc, 'Le Jura,' Paris, 1888; G. Boyer, 'Remarques sur l'Orographie des Monts Jura,' Besançon, 1888; and the older work of Thurmann, 'Esquisses Orographiques de la Chaine du Jura,' 1852.

[2] 'Geology of Uinta Mountains,' p. 201. There is in this work a suggestive discussion of types of mountain structure. See also Clarence King's 'Report on Geology of 40th Parallel,' vol. i.

the uplift has given way, and the resulting fault has at one point a vertical displacement estimated by him at 20,000 feet.

Another variety of more complex structure may be termed the *Park type*, from its singularly clear development in the Park region of

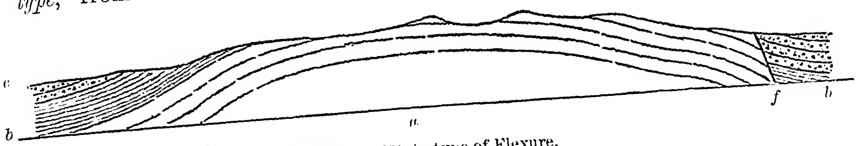

Fig. 501.—Uinta type of Flexure.
a, Palæozoic rocks; *b*, Mesozoic; *c*, Tertiary; *f*, fault.

Colorado. In this type, an axis of ancient crystalline rocks—granites, gneisses, &c.—has been as it were pushed through the flexure, or the younger strata have been bent sharply over it, so that after vast denudation their truncated ends stand up vertically along the flanks of the uplifted nucleus of older rocks (Fig. 502).

There may be only one dominant flexure, as in the case of the Uinta Mountains, the long axial line of which is truncated at the ends by lines

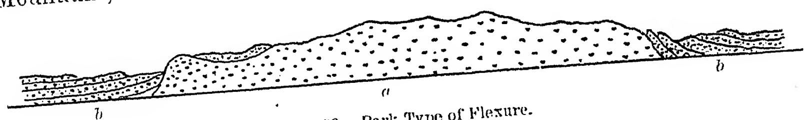

Fig. 502.—Park Type of Flexure.
a, Crystalline rocks; *b*, Mesozoic rocks.

of flexure nearly at right angles to it. More usually, numerous folds run approximately parallel to each other, as in the Jura and Appalachian chains. Not infrequently, some of them die out or coalesce. Their axes are seldom perfectly straight lines, but are frequently undulating or curved.

(*c*) *Unsymmetrical Flexures*, where one side of the fold is much steeper than the other, but where the two sides are still inclined in opposite directions, occur in tracts of considerable disturbance. The steep sides

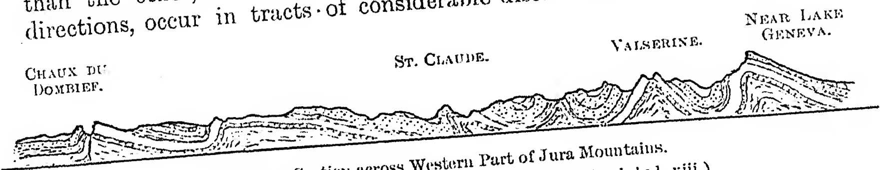

Fig. 503.—Section across Western Part of Jura Mountains.
(After P. Choffat, $\frac{1}{250000}$, A. Heim, 'Mechanism. Gebirgsb.' pl. xiii.)

look away from the area of maximum movement, and are more sharply inclined as they approach it, until the flexures become inverted. Instructive examples of this structure are presented by the Jura Mountains and the Appalachian chain. In these tracts, it is observable that in proportion as the flexures increase in angle of inclination, they become narrower and closer together; while, on the other hand, as they diminish into

symmetrical forms, they become broader, flatter, and wider apart, till they disappear (Figs. 253, 503).

(*d*) *Reversed Flexures*, where the strata have been folded over in such a way that on both sides of the axis of curvature they dip in the same direction, occur chiefly in districts of the most intense plication, such as a great mountain chain like the Alps. The inclination, as before, is for the most part towards the region of maximum disturbance, and the flexures are often so rapid that after denudation of the tops of the arches the strata are isoclinal, or appear to be dipping all in the same direction (p. 678). A gradation can be traced through the three last-named kinds of flexure. The inverted or reversed type is found where the crumpling of the crust has been greatest. Away from the area of maximum disturbance, the folds pass into the unsymmetrical type, then with gradually lessening slopes into the symmetrical, finally widening out and flattening into the plains. If we bisect the flexures in a section of such a plicated region we find that the lines of bisection or "axis-planes" are vertical in the symmetrical folds, and gradually incline towards the more plicated ground at lessening angles.[1]

Fractures not infrequently occur along the axis of unsymmetrical and inverted flexures, the strata having snapped under the great tension, and one side (in the case of inverted flexures, usually the upper side) having been pushed over the other, sometimes with a vertical displacement of several thousand feet, or a horizontal thrust of perhaps many miles (*ante*, pp. 690-694, 794, 892, 970). It is along or parallel to the axes of plication, and therefore coincident with the general strike, that the great faults of a plicated region occur. One of the most remarkable and important faults in the low grounds of Europe is that which bounds the southern edge of the Belgian coal-field (p. 693). It can be traced across Belgium, has been detected in the Boulonnais, and may not improbably run beneath the Secondary and Tertiary rocks of the south of England. The extraordinary thrust-planes which Rothpletz has shown to exist in the Alps, and those of the north-west of Scotland, are notable examples of gigantic horizontal displacements in mountainous regions, while still more prodigious are those of Scandinavia. It is a remarkable fact that faults which have a vertical throw of many thousands of feet may produce little or no effect upon the surface. The great Belgian fault just referred to is crossed by the valleys of the Meuse and other northerly flowing streams, yet so indistinctly is it marked in the Meuse valley that no one would suspect its existence from any peculiarity in the general form of the ground, and even an experienced geologist, until he had learned the structure of the district, would scarcely detect any fault at all. The Scottish thrust-planes are eroded like ordinary junction-planes between strata, and produce no more effect than these do on the topography (see Figs. 344, 369), nor have the still more stupendous displacements of the Alps and Scandinavia been more effective in the determination of the leading features of topography.

In some regions of intense disturbance the rocks have been plicated

[1] H. D. Rogers, *Trans. Roy. Soc. Edin.* xxi. p. 434.

rather than fractured. The folds have been so compressed that their opposite limbs often lie parallel to each other at a high inclination, though, as in the case of the Alps, closer scrutiny even in such tracts where plication has been so effective may discover proofs also of gigantic thrusts. In other regions, such as the north-west of Scotland, where the gigantic pressure has encountered the resistance of a "horst" or solid buttress of immovable material, the rocks have been ruptured by innumerable thrust-planes and faults, and have been driven over each other in a kind of imbricated structure (Fig. 369).

(e) *Alpine Type of Mountain-Structure.*[1]—It is along a great mountain chain like the Alps that the most colossal crumplings of the terrestrial crust are to be seen. In approaching such a chain, one or more minor ridges may be observed running on the whole parallel with it, as the heights of the Jura flank the north side of the Alps, and the sub-Himalayan hills follow the southern base of the Himalayas. On the outer side of these ridges, the strata may be flat or gently inclined. At first they undulate in broad gentle folds; but traced towards the mountains these folds become sharper and closer, their shorter sides fronting the plains, their longer slopes dipping in the opposite direction. This inward dip is often traceable along the flanks of the main chain of mountains, younger rocks seeming to underlie others of much older date. Along the north front of the Alps, for instance, the red molasse is overlain by Eocene and older formations: The inversions and disruptions increase in magnitude till they reach such colossal dimensions as those of the Glärnisch,[2] where pre-Cambrian schists, and Triassic, Jurassic, and Cretaceous rocks have been driven for miles over the Eocene and Oligocene flysch (pp. 677, 693). In such vast crumplings and thrusts it may happen that portions of older strata are caught in the folds of later formations, and some care may be required to discriminate the enclosure from the rocks of which it appears to form an integral and original part. Some of the recorded examples of fossils of an older zone occurring by themselves in a much younger group of plicated rocks may be thus accounted for.

The inward dip and consequent inversion traceable towards the centre of a mountain chain lead up to the fan-shaped structure (p. 678), where the oldest rocks of a series occupy the centre and overlie younger masses,

[1] For information on the internal structure of the Alpine chain see especially the maps, sections, and explanatory memoirs by Renevier, Heim, A. Baltzer, E. Favre, K. J. Kaufmann, C. Moesch, H. Schardt, A. Gutzwiller, E. von Fellenberg, and others in the *Beiträge zur Geol. Karte der Schweiz*; also Fritz Frech, "Die Karnischen Alpen," *Abhand. Naturf. Ges. Halle*, xviii. (Heft i.) 1892; Zaccagna on the Graian Alps, *Boll. Com. Geol. Ital.* ser. iii. vol. iii. (1892), p. 175; consult also Heim's 'Mechanismus der Gebirgsbildung'; Suess, 'Antlitz der Erde' and 'Entstehung der Alpen'; A. Favre, 'Recherches Géol. dans les parties de la Savoie du Piémont et de la Suisse voisines du Mont Blanc,' 1867, and 'Description Géol. Canton Genève,' 1880; E. Fraas, 'Scenerie der Alpen,' 1892; the writings of A. Rothpletz cited *ante*, p. 677; Duparc and Mrazec, 'Mont Blanc,' Geneva, 1898.

[2] Besides the great work of Heim on this region and the memoirs of Rothpletz cited *ante*, p. 677, see a paper by the latter in *Z. D. G. G.* xlix. (1897), p. 1; one by Baltzer, *op. cit.* li. (1899), p. 327; and further remarks by Rothpletz in same volume.

which plunge steeply under them. Classical examples of this structure occur in the Alps (Mont Blanc, Fig. 258, St. Gothard), where crystalline rocks such as granite, gneiss, and schist, the oldest masses of the chain, have been ridged up into the central and highest peaks. Along these tracts, denudation has been of course enormous, for the appearance of the granitic rocks at the surface has been brought about, not necessarily by actual extrusion into the air, but more probably by prolonged erosion, which in these higher regions, where many forms of sub-aerial waste reach their most vigorous phase, has removed the vast overarching cover of younger rocks under which the crystalline nucleus doubtless lay buried.

With the crumpling and fracture of rocks in mountain-making, the hot springs may be connected, which so frequently arise along the flanks of a mountain chain. A further relation is to be traced between these movements and the opening of volcanic vents along a mountain-chain or parallel to it, as in the Andes and other prominent ridges of the crust or along the crests of sub-oceanic ridges, as is so strikingly displayed in the Pacific and Atlantic basins. Elevation, by diminishing the pressure on the parts beneath the upraised tracts, may permit them to assume a liquid condition and to rise within reach of the surface, when, driven upwards by the expansion of superheated vapours, they are ejected in the form of lava or ashes. Mr. Fisher has suggested that the lower half of a double bulge of the crust in a mountain (p. 1366), by being depressed into a lower region, may be melted off, giving rise to siliceous lavas which may rise before the deeper basaltic magma begins to be erupted.

A mountain-chain may be the result of one movement, but probably in most cases is due to a long succession of such movements. Formed on a line of weakness in the crust, it has again and again given relief from the strain of compression by undergoing fresh crumpling and upheaval. Successive stages of uplift are usually not difficult to trace. The chief guide is supplied by unconformability (p. 820). Let us suppose, for example, that a mountain range (Fig. 504) consists of

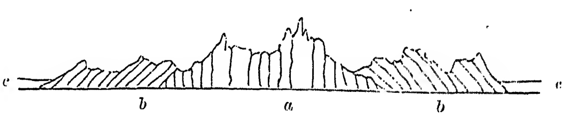

Fig. 504.—Section showing two periods of Upheaval.

upraised Lower Silurian rocks (*a*), upon the upturned and denuded edges of which the Carboniferous Limestone (*b b*) lies transgressively. The original upheaval of that range must have taken place between the Lower Silurian and the Carboniferous Limestone periods. If, in following the range along its course, we found the Carboniferous Limestone also highly inclined and covered unconformably by the Upper Coal-measures (*c c*), we should know that a second uplift of that portion of the ground had taken place between the time of the Limestone and that of the Upper Coal-measures. Moreover, as the Coal-measures were laid down at or below the sea-level, a third uplift has subsequently occurred

whereby they were raised into dry land. By this simple and obvious kind of evidence, the relative ages of different mountain chains may be compared. In most great mountain chains, however, the rocks have been so intensely crumpled, dislocated, and inverted, that much labour may be required before their true relations can be determined.

The Alps offer an instructive example of a great mountain system formed by repeated movements during a long succession of geological periods. The central portions of the chain consist of gneiss, schists, granite, and other crystalline rocks, partly referable to the pre-Cambrian series, but some of which (Schistes lustrés, Bündnerschiefer) include metamorphosed Palæozoic, Secondary, and in some places, perhaps, even older Tertiary deposits (pp. 802, 1099). It would appear that the first outlines of the Alps were traced out even in pre-Cambrian times, and that after submergence, and the deposit of Palæozoic formations along their flanks, if not over most of their site, they were re-elevated into land. From the relations of the Mesozoic rocks to each other, we may infer that several renewed uplifts, after successive denudations, took place before the beginning of Tertiary times, but without any general and extensive plication. A large part of the range was certainly submerged during the Eocene period under the waters of that wide sea which spread across the centre of the Old World, and in which the nummulitic limestone and flysch were deposited. But after that period the grand upheaval took place to which the present magnitude of the mountains is chiefly due. The older Tertiary rocks, previously horizontal under the sea, were raised up into mountain-ridges more than 11,000 feet above the sea-level, and, together with the older formations of the chain, underwent colossal plication and displacement. Enormous slices of the oldest rocks were torn away from the foundations of the chain and driven horizontally for miles until they came to rest upon some of the newest formations. The thick Mesozoic groups were folded over each other like piles of carpets, and involved in the lateral thrusts so as now to be seen resting upon the Tertiary flysch. So intense was the compression and shearing to which the rocks were subjected that lenticles of the Carboniferous series have been folded in among Jurassic strata, and the whole have been so welded together that they can hardly be distinguished where they meet, and what were originally clays and sands have been converted into hard crystalline rocks. It is strange to reflect that the enduring materials out of which so many of the mountains, cliffs, and pinnacles of the Alps have been formed are of no higher geological antiquity than the London Clay and other soft Eocene deposits of the south of England and the north of France and Belgium. At a later stage of Tertiary time, renewed disturbance led to the destruction of the lakes in which the molasse had accumulated, and their thick sediments were thrust up into large broken mountain masses, such as the Rigi, Rossberg, and other prominent heights along the northern flank of the Alps. Since that last post-Eocene movement, no great orogenic paroxysm seems to have affected the Alpine region. But the chain has been left in a state of unstable equilibrium. From time to time normal faults have taken place whereby portions of

the uplifted rocks have sunk down for hundreds of feet, and some of these dislocations have cut across the much older and more gigantic displacements of the thrust-planes (Fig. 282). At the same time continuous denudation has greatly transformed the surface of the ground, so that now cakes of gneiss are left as mountainous outliers upon a crushed and convoluted platform of Tertiary strata.[1] Nor, in spite of the settling down of these broken masses, has final stability been attained. The frequent earthquakes of the Alpine region bear witness to the strain of the rocks underneath, and the relief from it obtained by occasional rents propagated through the crust along the length of the chain.

The epeirogenic evolution of a continent during a long succession of geological periods has been admirably worked out for the whole globe by Suess, for Europe by him and by Neumayr, and for North America by Dana, Dawson, Dutton, Gilbert, Hayden, King, Newberry, Powell, and others. The general character of the structure of the American continent is extreme simplicity, as compared with that of the Old World. In part of the Rocky Mountain region, for example, while the Palæozoic formations lie unconformably upon pre-Cambrian gneiss, there is, according to King, a regular conformable sequence from the lowest Palæozoic to the Jurassic rocks, though probably many local unconformabilities exist. During the enormous interval of time represented by these massive formations, what is now the present axis of the continent appears to have been exempt from any great orogenic paroxysm and to have remained hardly disturbed by more than a gentle and protracted subsidence. In the great depression or geosyncline thus produced, all the Palæozoic and a great part of the Mesozoic rocks were accumulated. At the close of the Jurassic period, the first great upheavals took place. Two lofty ranges of mountains—the Sierra Nevada (now with summits more than 14,000 feet high) and the Wahsatch—400 miles apart, were pushed up from the great subsiding area. These movements were followed by a prolonged subsidence, during which Cretaceous sediments accumulated over the Rocky Mountain region to a depth of 9000 feet or more. Then came another vast uplift, whereby the Cretaceous sediments were elevated into the crests of the mountains, and a parallel coast-range was formed fronting the Pacific. Intense metamorphism of the Cretaceous rocks is stated to have taken place. The Rocky Mountains, with the elevated table-land from which they rise, now permanently raised above the sea, were gradually elevated to their present height. Vast lakes filled depressions among them, in which, and on the plains in front of the mountains, as in the Tertiary basins of the Alps and the Gondwana series of the Himalaya, enormous masses of sediment accumulated. The slopes of the land were clothed with an abundant vegetation, in which we may trace the ancestors of many of the living trees of North America. One of the most striking features in the later phases of this history was the outpouring of great floods of trachyte, basalt, and other lavas from many points and fissures

[1] These features of Alpine tectonics have been admirably deciphered by Dr. Rothpletz in the series of memoirs already cited.

over a vast space of the Rocky Mountains and the tracts lying to the west. In the Snake River region alone the basalts have a depth of 700 to 1000 feet, over an area 300 miles in breadth.

These examples show that the elevation of mountains, like that of continents, has been occasional, and probably sometimes paroxysmal. Long intervals elapsed, when a slow subsidence took place, but at last a point was reached when the descending crust, unable any longer to withstand the accumulated lateral pressure, was forced to find relief by rising into mountain ridges. With this effort the elevatory movements ceased for the time. They were followed either by a stationary period, or more usually by a renewal of the gradual depression, until eventually relief was again obtained by upheaval, sometimes along new lines, but often on those which had previously been used. The intricate crumpling and gigantic displacements and inversions of a great mountain-chain naturally suggest that the movements which caused these disturbances of the strata were sudden and violent. And this inference may often, if not generally, be correct. It is not so easy, however, to demonstrate that a disturbance was rapid as to prove that it must have been slow. That some uplifts resulting in the rise of important mountain ranges have been almost insensibly brought about, is believed to be shown by the operation of rivers in the regions affected. Thus the rise of the Uinta Mountains appears to have been so quiet, that the Green River, which flowed across the site of the range, has not been deflected, but has actually been able to deepen its cañon as fast as the mountains have been pushed upward.[1] The Pliocene accumulations along the southern flanks of the Himalayas show that the rivers still run in the same lines as they occupied before the last gigantic upheaval of the chain (p. 1297).[2] A similar conclusion has been drawn from the river-valleys in the Elburz Mountains, Persia.[3]

2. Terrestrial Features due to Volcanic Action.—The two types of volcanic eruptions described in Book III. Part I. give rise to two very distinct types of scenery. The ordinary volcanic vent leads to the piling up of a conical mass of erupted materials round the orifice. In its simplest form, the cone is of small size, and has been formed by the discharges from a single funnel, like many of the tuff and cinder-cones of Auvergne, the Eifel, the Bay of Naples, the Permian necks of Central Scotland, the Tertiary vents of the Swabian Alb, and the youngest cones in the volcanic tracts of the western United States. Every degree of divergence from this simplicity may be traced, however, till we reach a colossal mountain like Etna, wherein, though the conical form is still retained, eruptions have proceeded from so many lateral vents that the

[1] Powell's "Geology of the Uinta Mountains," in the Reports of *U.S. Geographical and Geological Survey Rocky Mountain Region*, 1876. The same conclusion is drawn by Gilbert from the structure of the Wahsatch Mountains. See his admirable essay on "Land Sculpture," in his "Geology of the Henry Mountains," published in the same series of Reports, 1877.

[2] Medlicott and Blanford, 'Geology of India,' p. 570.

[3] E. Tietze, *Jahrb. Geol. Reichsanst.* xxviii. (1878), p. 581.

main cone is loaded with minor volcanic hills, or like some of the still more gigantic peaks of Ecuador, where such huge masses of solid rock form the central and loftiest part of the structure. Denudation as well as explosion comes into play; deep and wide valleys, worn down the slopes, serve as channels for successive floods of lava or of water and volcanic mud. On the other hand, the type of fissure-eruption in which the lava, instead of issuing from a central vent, has flowed out from minor vents along the lines of many parallel or connected fissures, leads to the formation of wide lava-plains composed of successive level sheets of lava. By subsequent denudation, these plains are trenched by valleys, and, along their margin, are cut into escarpments with isolated blocks or outliers. Thus, while at first they look like lakes or seas of black verdureless rock, as in the modern lava-deserts of Iceland, or those of more ancient date in the Western United States, they eventually become great plateaux or table-lands trenched by deep and wide valleys or cut into tall cliffs by the sea, like those of north-west Europe, the Deccan, Abyssinia, and the Snake River.

The forms assumed by volcanic masses of older Tertiary and still earlier geological date are in the main due not to their original contours, but to denudation. The rocks, being commonly harder than those among which they lie, stand out prominently, and often, in course of time and in virtue of their mode of weathering, assume a conical form, which, however, has usually no relation to that of the original volcano. Eminences formed after the type of the Henry Mountains (p. 736) owe their dome-shape to the subterranean effusion of erupted lava, but the superficial irregularities of contour in the domes must be ascribed to denudation (Figs. 301, 324, 326, 328, 329, 338).

3. Terrestrial Features due to Denudation.—The general results of denudation have been discussed in Book III. Part II. Sect. ii.[1] Every portion of the land, as soon as it rises above the sea-level, is attacked by denuding agents. Hence the older a terrestrial surface, the more may it be expected to show the results of the operation of these agents. We have already seen how comparatively rapid are the processes of subaerial waste (pp. 586-597). It is accordingly evident that the present contours of the land cannot be expected to reveal any trace whatever of the early terrestrial surfaces of the globe. The most recent mountain chains and volcanoes may, indeed, retain more or less markedly their original superficial outlines; but these must be more and more effaced in proportion to their geological antiquity.

[1] The part taken by denudation in landscape has been much discussed. It was strongly enforced by Hutton in his 'Theory of the Earth,' and by Playfair in his 'Illustrations of the Huttonian Theory.' The views of these pioneers were adopted and worked out in some detail by Jukes (*postea*, p. 1384), afterwards by Ramsay in his volume cited on p. 1364, by myself in my 'Scenery of Scotland,' and by Topley and Foster with reference to the Weald of the South of England (*Mem. Geol. Survey*, 1875). Since these early writings the subject has been taken up with great enthusiasm in the United States, especially by Powell and Gilbert. Professor W. M. Davies has also written voluminously upon it. To some of his papers reference is made in subsequent pages. The subject is discussed in the volume 'Les Formes du Terrain,' by MM. De la Noë and De Margerie.

The fundamental law in the erosion of terrestrial surfaces is that harder rocks resist decay more, while softer rocks resist it less. The former consequently are left projecting, while the latter are worn down. The terms "hard" and "soft" are used here in the sense of being less easily and more easily abraded, though every rock suffers in some measure. If, therefore, a perfectly level surface, composed of rocks exceedingly unequal in power of resistance, were to be raised above the sea, and to be exposed to the action of weathering, it would eventually be carved into a system of ridges and valleys. The prominences would be largely determined by the position of the harder rocks, the depressions by the site of the softer. But no surface of land in nature is perfectly smooth and level. There are always undulations and inequalities which, though they may be imperceptible to the eye, make themselves conspicuous when rain falls, for even the faintest hollows then become pools or serve as channels for the descent of the water to lower levels. Hence, whether by initial inequalities of surface, or by varying degrees of softness, every mass of land, as soon as it is upraised above sea-level, begins to be unequally eroded. The hollows and valleys mark, on the whole, where the denudation is greatest. The hills and prominent ridges are found to be where they are, not so much because they have there been more upheaved, but because, by the disposition of the original drainage-lines, they have been less eroded than the valleys, or because they are composed of more durable materials.

In this marvellous process of land-sculpture, we have to consider, on the one hand, the agents and combinations of agents which are at work, and on the other, the varying powers of resistance arising from declivity, composition, and structure of the materials on which these agents act. The forces or conditions required in denudation—air, aridity, rapid alternations of moisture and drought or of heat and cold, rain, springs, frosts, rivers, glaciers, the sea, plant and animal life—have been described in Book III. Part II. Every country and climate must obviously have its own combination of erosive activities. The decay of the surface in Egypt or Arizona arises from a different group of forces from that which can be seen in the west of Europe or in New England.

In tracing the sculpture of the land, we are soon led to perceive the powerful influence of the angle of slope of the ground upon the rate of erosion. This rate decreases as the angle lessens, till on level plains it reaches its minimum. Other things being equal, a steep mountain ridge will be more deeply eroded than a gentle elevation of equal height which rises gradually out of the plains. Hence the declivity of the ground, at its first uplift into land, must have had an important bearing upon the subsequent erosion of the slopes. It is important to observe that the depressions into which the first rain gathered on the surface of the newly upraised land would, in most cases, become the permanent lines of drainage. They would be continually deepened as the water coursed in them, so that, unless where subterranean disturbance came into play, or where the channels were obstructed by landslips, volcanic ejections, or otherwise, the streams would be unable to quit the channels

they had once chosen. The permanence of drainage-lines is one of the most remarkable features in the geological history of the continents. The main valleys of a country are usually among the oldest parts of its topography. As they are widened and deepened, the ground between

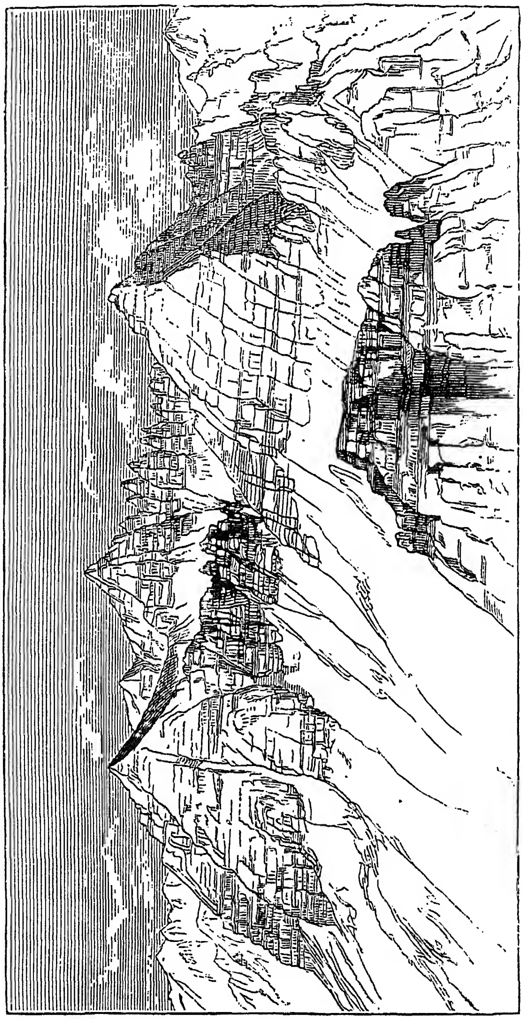

Fig. 505.—Outlines of Mountains formed of nearly horizontal Stratified Rocks. Rocky Mountains. (Hayden's 'Report of Survey of Western Territories,' 1874.)

them may be left projecting into high ridges and even into prominent isolated hills.

A chief element in the progress of land-sculpture is geological structure—the character, arrangement, and composition of the rocks, and the manner in which each variety yields to the attacks of the denuding agents. Besides the general relations of the so-called hard rocks

to resulting prominences, and of soft rocks to depressions, the broader geotectonic characters have had a dominant influence upon the evolution of terrestrial contours. As illustrations of this influence, reference may be made to the marked difference between the scenery of districts composed of stratified sedimentary rocks, and that of areas of massive eruptive rocks, such as granite. In the former case (Fig. 505), bedding and joints furnish divisional lines, the guiding influence of which upon the external forms of the mountains is everywhere traceable. In the case of eruptive masses (Fig. 506), the rock is split open along joints only, which mainly determine the shapes of crest, cliff, and corry.

Bedding produces a distinct type of scenery which can be traced from the sides of a mere brook up into tall sea-cliffs or into lofty mountain-groups. Moreover, much of the ultimate character of the scenery depends upon whether the strata have been left undisturbed; for the position of the bedding, whether flat, inclined, vertical, or contorted, largely determines the nature of the surface. The most characteristic scenery formed by stratified rocks is undoubtedly where the bedding is horizontal, or nearly so, and the strata are massive. A mountain constructed of such materials appears as a colossal pyramid, the level bars of stratification looking like gigantic courses of masonry. Joints and faults traversing the bedding allow it to be cleft into blocks and deep chasms that heighten the resemblance to ruined architecture. Impressive illustrations of these results are to be found in the Western Territories of the United States. The vast table-lands of the River Colorado, in particular, offer a singularly impressive picture of the effects of mere subaerial erosion on undisturbed and nearly level strata (see Frontispiece). Systems of stream-courses and valleys, river gorges, unexampled elsewhere in the world for depth and length, vast winding lines of escarpment, like ranges of sea-cliffs, terraced slopes rising from plateau to plateau, huge buttresses and solitary stacks standing like islands out of the plains, great mountain masses towering into picturesque peaks and pinnacles, cleft by innumerable gullies, yet everywhere marked by the parallel bars of the horizontal strata out of which they have been carved—these are the orderly symmetrical characteristics of a country where the scenery is due entirely to the action of subaerial agents and the varying resistance of level or little disturbed stratified rocks.

On the other hand, where stratified rocks have been subjected to plications and fractures, their characteristic features may be gradually almost lost among those of the crystalline masses which under these circumstances are so often found to have been forced through them. The Alps may be cited as a well-known example of this kind of scenery (Figs. 255-258, 282). The whole geological aspect of these mountains is suggestive of former intense commotion. Yet on every side proofs of the most enormous denudation meet the eye. Twisted and crumpled, the solid sheets of limestone may be seen as it were to writhe from the base to the summit of a mountain, yet they present everywhere their truncated ends to the air, and from these ends it is easy to see that a vast amount of material has been worn away. Apart altogether from what may have been the

shape of the ground immediately after the upheaval of the chain, there is evidence on every side of gigantic denudation. The subaerial forces that have been at work upon the Alpine surface ever since it first appeared have dug out the valleys, sometimes acting in original depressions, sometimes eroding hollows down the slopes. Moreover they have planed down

Fig. 506.—Outlines of a Mountain formed of Massive (Igneous) Rocks. Rocky Mountains. (Hayden's 'Report of Survey of Western Territories,' 1874.)

the flexures, excavated lake-basins, scarped the mountain sides into cliff and *cirque*, notched and furrowed the ridges, splintered the crests into chasm and *aiguille*, until no part of the original surface now remains in sight. And thus the Alps remain a marvellous monument of stupendous earth-throes, followed by prolonged and gigantic denudation

In massive or igneous rocks, the structure-lines are those of joints alone, and according to the direction of the intersecting joints the trend and shape of the ridges are determined. The importance of rock-joints, not only in details of scenery, but even in some of the main features of the mountain outlines of massive rocks, and in the erosion of ravines is hardly at first credible. It is along these divisional lines that the rain has filtered, and the springs have risen, and the frost wedges have been driven. On the bare scarps of a high mountain, where the inner structure of the mass is laid open, the system of joints is seen to have determined the lines of crest, the vertical walls of cliff and precipice, the forms of buttress and recess, the position of cleft and chasm, the outline of spire and pinnacle. On the lower slopes, even under the tapestry of verdure which nature delights to hang where she can over her naked rocks, we may detect the same pervading influence of the joints upon the forms assumed by ravines and crags. Each kind of eruptive rock has its own system of joints, and by these in large measure is its characteristic type of scenery determined.

A few of the more important features of the land may be briefly noticed here in their relation to this branch of geology. In the physiography of any region, mountains are the dominant features (p. 50). A true mountain-chain consists of rocks that have been crumpled and pushed up in the manner already described. But ranges of hills, almost mountainous in their bulk, may be formed by the gradual erosion of valleys out of a mass of original high ground. In this way, some ancient table-lands have been so channelled that they now consist of massive rugged hills, either isolated or connected along the flanks. Eminences detached by erosion from the masses of rock whereof they once formed a part, have been termed *outliers* (Figs. 124, 507, 508), or where of large size, *hills of circumdenudation*. Their isolation may either be due to the action of streams working round them, apart altogether from geological structure, or to their more resisting constitution, which has enabled them to remain prominent during the general degradation of the whole surface.

Table-lands (p. 53) may sometimes arise from two causes. In the first place, wide tracts of horizontal stratified rocks, whether of aqueous or of igneous origin, may be elevated by epeirogenic movements until, still preserving their general horizontality, they reach a height of hundreds or thousands of feet above the sea. In such cases the surface of the platform may at first correspond broadly with that of the stratification, though the progress of denudation tends continually to destroy the connection between the two surfaces. Such examples are *Tablelands of Deposition*. In the second place, a tableland may be formed by the abrasion of hard rocks and the production of a more or less level plain as the result of denudation. This process can only be completed when the land has been worn down by such long continued degradation that its level is not much above that of the sea, and its slopes are so feeble that erosion almost ceases.[1] But the result is most completely attained when the worn down platform has been finally levelled out by the waves of the sea and depressed below sea-level to the lower limit of marine erosion. Such a

[1] Professor Davis has proposed the term "peneplain" for such a denuded platform.

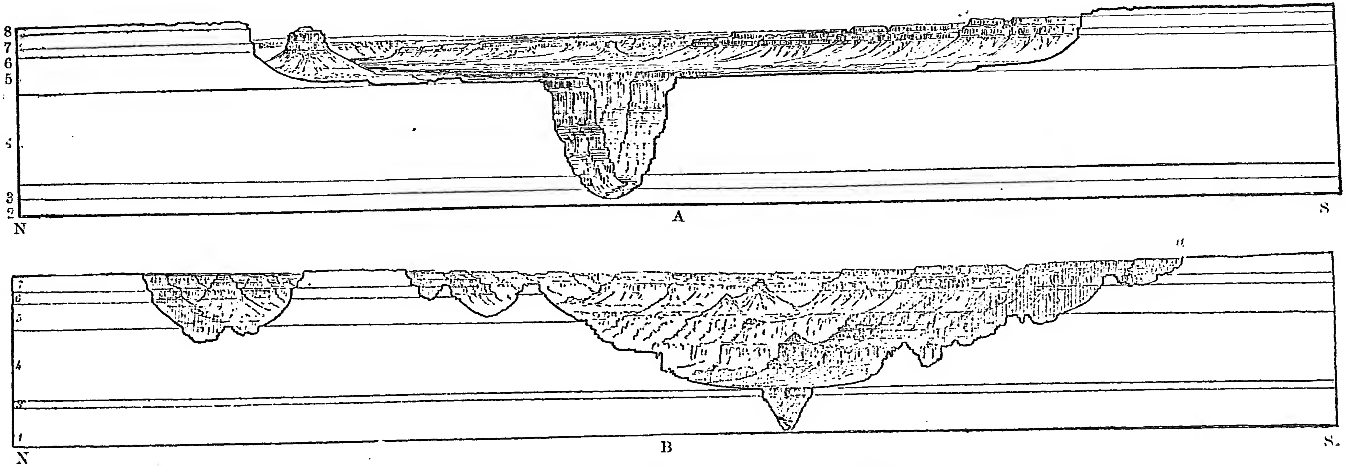

Fig. 507.—Sections across the Grand Cañon of the Colorado.[1]

(Vertical and Horizontal Scale the same.)

A. Section in the Kanab division. B. Section in the Kaibab division. *a* to *a* seven miles.

		Thickness in A.	Thickness in B.
Permo-Carboniferous	8. Bellerophon beds	250 ft.	—
Coal-measures	7. Cherty Limestone	350 „	500 ft.
	6. Cross-bedded Sandstone	200 „	400 „
	5. Aubrey red Shales, &c.	1200 „	900 „
Lower Carboniferous	4. Red Wall	2500 „	2200 „
	3. Tonto Group	300 „	200 „
	2. Silurian rocks (covered unconformably by overlying rocks)	300 „	—
	1. Granite, Schist, &c., eroded before deposition of Carboniferous rocks	—	1200 „

[1] Drawn on a true scale for this work by Prof. Holmes, whose diagrams of the geological structure and scenery of Western America are probably at once the most artistic and instructive sketches with which geological literature has yet been enriched. To his graphic pencil also the author owes the Frontispiece to this volume.

form of surface, when raised into high land, becomes a *Table-land of Erosion.* Notable examples are to be seen in the extensive "fjelds" or elevated plateaux of Scandinavia, many of which, rising above the snow-line, form vast snow-fields whence glaciers descend almost to the sea-level. Fragments of a similar table-land may be recognised among the Grampian Mountains of Scotland. It can be shown that some of these plateaux are of high antiquity, that they have been protected for ages by formations now worn away from them, and that they are being gradually destroyed by the denuding forces. Most of the great table-lands of the globe seem to be platforms of the first type. But, whatsoever its mode of origin, the plateau undergoes a gradual transformation under continued denudation. No sooner are the rocks raised above the sea, than they are attacked by running water, and begin to be hollowed out into systems of valleys. As the valleys sink, the platforms between them grow into narrower and more definite ridges, until eventually the level table-land is converted into a complicated network of hills and valleys, wherein, nevertheless, the key to the whole arrangement is furnished by a knowledge of the disposition and effects of the flow of water. The examples of this process brought to light in Colorado, Wyoming, Nevada, and the other Western Territories, by Newberry, King, Hayden, Powell, Gilbert, Dutton, and other explorers, are among the most striking monuments of geological operations in the world. The erosion of the ancient table-lands of Scandinavia and Scotland, and their conversion into systems of hilly ridges and valleys, have been a more complex process, prolonged through a succession of geological periods with intervals of upheaval and depression, but though less impressive from its more limited scale, it conveys many interesting and instructive lessons as to the efficacy of subaerial waste.[1]

Watersheds are of course at first determined by the form of the earliest terrestrial surface. But they are less permanent than the water-courses that diverge from them. Where a watershed lies symmetrically along the centre of a country or continent, with an equal declivity and rainfall on either side, and an identity of geological structure, its site will be permanent, because the erosion on each slope proceeds at the same rate. But such a combination of circumstances can happen rarely, save on a small and local scale. As a rule, watersheds lie on one side of the centre of a country or continent, and the declivity is steeper on the side nearest the sea. Hence, apart from any influence from difference of geological structure, the tendency of erosion, by wearing the steep slope more than the gentle one, is to carry the watershed backward nearer to the true centre of the region, especially at the heads of valleys. Of course this is an extremely slow process; but it must be admitted to be one of real efficacy in the vast periods during which denudation has continued. Excellent illustrations of its progress, as well as of many other features of land-sculpture, may often be instructively studied on clay-banks exposed to the influence of rain.[2]

[1] The plateau of the Ardennes is another instance of a tableland of erosion cut in ancient plicated rocks. Its erosion is noticed by H. Arctowski, *B. S. G. F.* xxiii. (1895), p. 3.

[2] See on this subject Mr. Gilbert's suggestive remarks in the Essay on 'Land Sculpture'

The crests of mountains are watersheds of the sharpest type, where erosion has worked backward upon a steep slope on either side. Their forms are mainly dependent upon structure, and especially upon systems of joints. It will often be observed that the general trend of a crest coincides with that of one set of joints, and that the bastions, recesses, and peaks have been determined by the intersection of another set. If the rock is uniform in structure, and the declivity equal in angle on either side, a crest may retain its position; but as one side is usually considerably steeper than the other, the crest advances at the expense of the top of the gentler declivity. But, under any circumstances, it is continually lowered in level, for it may be regarded as the part of a mountain where the rate of subaerial denudation reaches a maximum. An ordinary cliff is attacked in front, but a crest has two fronts, and is further splintered along its summit. Nowhere can the guiding influence of geological structure be more conspicuously seen than in the array of spires, buttresses, gullies, and other striking outlines which a mountain crest assumes.

Valleys have had their direction determined (1) by flexures of the terrestrial crust; (2) by lines of fault; or (3) by original inequalities on the surface of an uplifted platform of denudation. It is much less common than might be supposed to find a valley lying along a synclinal trough, though some of the larger depressions parallel with the strike of the plication in a mountain-chain have obviously had this origin. Again, the coincidence of valleys with lines of fault is probably much less frequent than is often supposed. To many geologists the mere existence of a valley is evidence of the presence of a fault. In every case actual proof of the fault should be sought in the tectonic structure of the ground. The detailed mapping of the Geological Survey of Britain has shown that in the vast majority of cases in that country valleys have no connection with faults.[1] Where the disposition of a system of valleys has been determined by forms of surface due to the uplift of a mass of land above sea-level two dominant trends may be observed among them. There is first a *longitudinal* series corresponding to the strike of the flexures in the upraised ridge, and secondly a transverse series formed by the flow of the water down the slopes into the longitudinal valleys or into the sea. But even in these cases, for the most part little more than the initial direction is due to underground movement. The actual formation of valleys has been mainly the work of erosion.[2] Their contours depend partly on the

already cited (p. 1375). See also A. G., *Nature*, xxix. (1884), p. 325, where the history of the watersheds of the British Isles is traced, and where a general outline of the physiography of the country is given.

[1] Lord Avebury mentions that on the St. Gothard railway line the tunnels pass six times under the Reuss and that no fault occurs there ('Scenery of England,' p. 294). Perhaps the most remarkable coincidence of a long line of depressions and valleys with a powerful rupture of the terrestrial crust is that of the "Great Rift Valley" of Eastern Africa.

[2] The student should read the suggestive essay by the late J. B. Jukes (*Q. J. G. S.* xviii. (1862), p. 378), which was the first attempt to work out the history of the excavation of a valley system in reference to the geological history of the ground. See also Penck, *Neues Jahrb.* 1890, p. 165; E. Tietze, *Jahrb. Geol. Reichsanst.* xxxviii. (1888), p. 633.

structure and composition of the rocks, and partly on the relative potency of the different denuding agents. Where the influence of air, rain, frost, and general subaerial weathering has been slight, and the streams, supplied from distant sources, have had sufficient declivity, deep, narrow, precipitous ravines or gorges have been excavated. The cañons of the Colorado are a magnificent example of this result (Frontispiece and Figs. 124, 507). Where, on the other hand, ordinary atmospheric action has been more rapid, the sides of the river channels have been attacked, and open sloping glens and valleys have been hollowed out. A gorge or defile is usually due to the action of a waterfall, which, beginning with some abrupt declivity or precipice in the course of the river when it first commenced to flow, or caused by some hard rock crossing the channel, has eaten its way backward, as already explained (p. 500).

A pass is a portion of a watershed which has been cut down by the erosion of two valleys, the heads of which adjoin on opposite sides of a ridge. Each valley is cut backward until the intervening ridge is at that place much lowered or even demolished. Most passes no doubt lie in original but subsequently deepened depressions between adjoining mountains. The continued degradation of a crest may obviously give rise to a pass.

Lakes have been formed in four several ways.[1] 1. By subterranean movements, as, for example, in mountain-making and in volcanic explosions. The subsidence of the central part of a mountain system may depress the heads of the valleys below the level of portions farther from the sources of the stream. Or the elevation of the lower parts of the valleys may cause an accumulation of water in their upper parts. We have seen how seriously the uplift in Scandinavia and in Canada and the northern United States is affecting the drainage in those regions (pp. 381, 387). Or a lake-basin may be due to a special subsidence. 2. By irregularities in the deposition of superficial accumulations prior to the elevation of the land, or, in the northern parts of Europe and America, during the disappearance of the ice-sheet. The numerous tarns and lakes enclosed within mounds and ridges of drift-clay and gravel are examples. 3. By the accumulation of a barrier across the channel of a stream and the consequent ponding back of the water. This may be done, for instance, by a landslip, by a lava-stream, by the advance of a glacier across a valley, or by the throwing up of a bar by the sea across the mouth of a river. 4. By erosion. Water keeping stones in gyration can dig out pot-holes in the bed of a river or on the sea-shore. Unequal subaerial weathering may cause rocks to rot much more deeply in some places than in others, so that, on the removal of the rotted material, the surface of the solid rock might be full of depressions. But the only known agent capable of excavating such hollows as might form rock-basin lakes is glacier-ice

[1] For the literature connected with lakes see the various publications cited *ante*, p. 518. The most complete account of the lakes of any country is to be found in the admirable monograph of M. Delebecque, 'Les Lacs Français,' while the most detailed treatise on any single lake is the great work of Prof. Forel, 'Le Leman: Monographie limnologique,' of which the first part of the third volume, devoted to the biology of the lake, has appeared as these pages are passing through the press.

(p. 552). It is a remarkable fact, of which the significance may now be seen, that the innumerable lake-basins of the northern hemisphere lie, for the most part, on surfaces of intensely ice-worn rock. The striæ can be

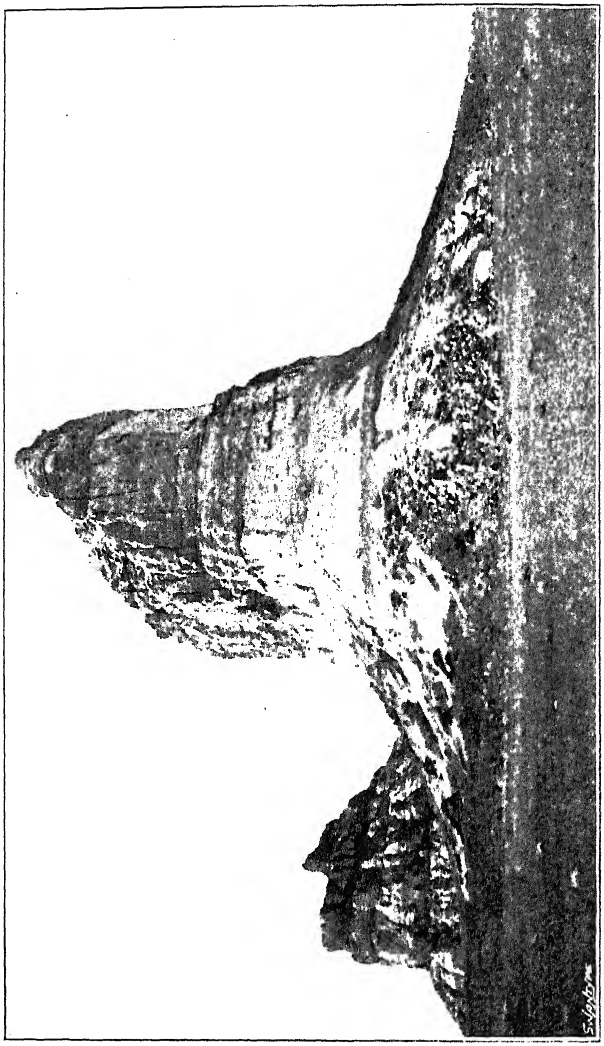

Fig. 508.—"Jail and Court-house Rocks."

Typical outliers or "buttes" of soft horizontal sandstone, developed by atmospheric denudation in a semi-arid region. Platte River, Western Nebraska (Photograph by Mr. N. H. Darton, U.S. Geol. Survey.)

seen on the smoothed rock-surfaces slipping into the water on all sides. These striæ were produced by ice moving over the rock. If the ice could, as the striæ prove, descend into the rock-basins and mount up the farther side, smoothing and striating the rock as it went, it could, to a certain depth at least, erode basins.

To what cause any particular lake basin is to be ascribed must be determined in each case by an examination of its local evidence. Obviously in some regions all the four modes of origin may have been at work. A lofty mountain-chain, if still subject to underground movements, might sink in its central axis or have a subsidiary uplift along its borders, with the result of ponding back the drainage of the valleys and giving rise to a series of lakes. At the same time, its glaciers might be scouring out rock-basins on the floors of the valleys, which might eventually be filled with water and form lakes, or the moraines might be so irregularly thrown down as to enclose tarns between their mounds and ridges; or lastly, avalanches sweeping down detritus from the higher slopes might dam up the drainage of some valleys and thus give rise to lakes.

In any case it is obvious that as detritus is continually being washed or blown into these sheets of water, our present lakes cannot be of any great geological antiquity. We see, indeed, all over the northern part of Europe and North America, that numerous as the lakes still are, they form only a small proportion of those that came into existence after the Ice Age, for innumerable examples may be observed of alluvial plains and peat-bogs which mark where lakes once existed. And everywhere we may trace how those which still remain are being filled up by the creeping of marshy vegetation into their waters, by the influence of rain and wind in removing into them the fine particles of the soil from their surrounding slopes, and by the growth of the deltas of the streams that flow into them.

In the general subaerial denudation of a country, innumerable minor features are worked out as the structure of the rocks controls the operations of the eroding agents. Thus, among undisturbed or gently inclined strata, a hard bed resting upon others of a softer kind is apt to form along its outcrop a line of cliff or escarpment, as in the "mesas" and "buttes" of the western United States (Figs. 124, 507). Though a long range of such cliffs resembles a coast that has been worn by the sea, it may be entirely due to mere atmospheric waste. Again, the more resisting portions of a rock may be seen projecting as crags or knolls. An igneous mass will stand out as a bold hill from amidst the more decomposable strata through which it has risen (Fig. 324). These features, often so marked on the lower grounds, attain their most conspicuous development among the higher and barer parts of the mountains, where subaerial disintegration is most rapid. The torrents tear out deep gullies from the sides of the declivities. Corries or cirques, if not originally scooped out by converging streamlets (their mode of formation is a somewhat difficult problem), are at least enlarged by this action, and their naked precipices are kept bare and steep by the wedging off of successive slices of rock along lines of joint. Harder bands of rock project as massive ribs upon the slopes (Fig. 338), shoot up into prominent peaks, or, with the combined influence of joints and faults, give to the summits the notched saw-like outlines they so often present.

The materials worn from the surface of the higher are spread out over the lower grounds. We have traced how streams at once

begin to drop their freight of sediment when, by the lessening of their declivity, their carrying power is diminished (p. 504). The great plains of the earth's surface are due to this consequent deposit of gravel, sand, and loam. They are thus monuments at once of the destructive and reproductive processes which have been in progress unceasingly since the first land rose above the sea and the first shower of rain fell. Every pebble and particle of the soil of the plains, once a portion of the distant mountains, has travelled slowly and fitfully downward. Again and again have these materials been shifted, ever moving seaward. For centuries, perhaps, they have taken their share in the fertility of the plains and have ministered to the nurture of flower and tree, of the bird of the air, the beast of the field, and of man himself. But their destiny is still the great ocean. In that bourne alone can they find undisturbed repose, and there, slowly accumulating in massive beds, they will remain until, in the course of ages, renewed upheaval shall raise them into future land, and thereby enable them once more to pass through a similar cycle of change.

INDEX OF AUTHORS QUOTED OR REFERRED TO

To facilitate reference it may be stated here that pages 1 to 702 are contained in Vol. I., and pages 705 to 1388 in Vol. II.

INDEX OF SUBJECTS

An asterisk attached to a number denotes that a figure of the subject will be found on the page indicated. Genera and species of fossils are printed in italics, except where they are used as marking stratigraphical subdivisions. Each genus is generally enumerated only once in each stratigraphical system in which it occurs, but occasionally, especially where its occurrence is of marked interest or importance, additional insertions are made.

THE END

Printed by R. & R. Clark, Limited, *Edinburgh*.